THE ROYAL AERONAUTICAL SOCIETY WAS FOUNDED IN 1866

JULY, 1944
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which is incorporated The Institution of Aeronautical Engineers

Edited for the Council by Capt. J. LAURENCE PRITCHARD, Hon. Fellow

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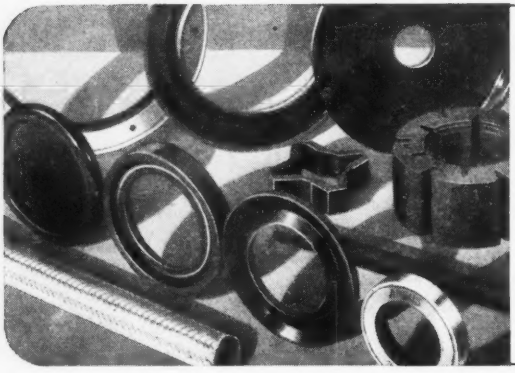

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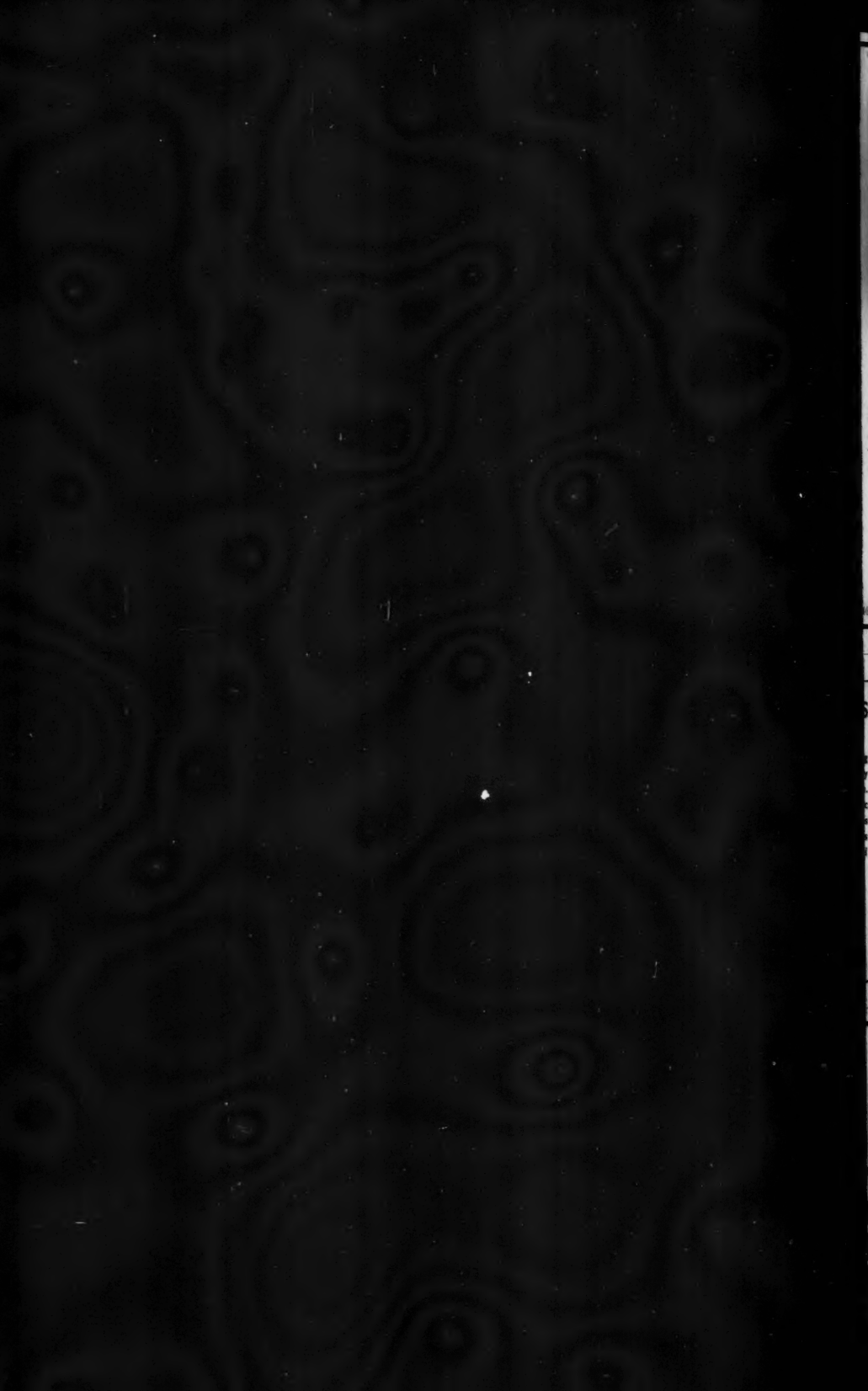

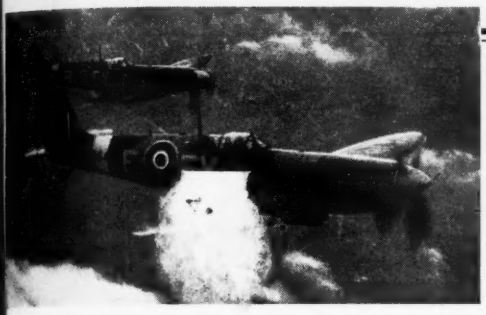

SPITFIRES WIN FIRST AIR CLASH OVER BEACHES

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The Daily Telegraph and Morning Post, 8-6-44

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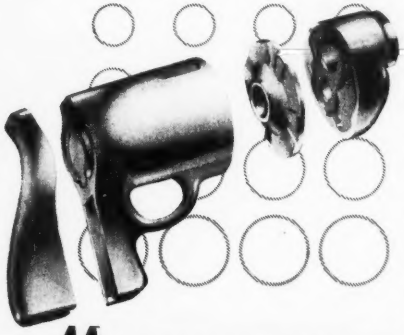

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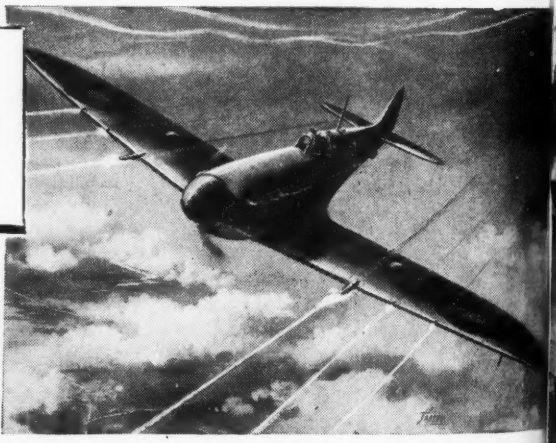

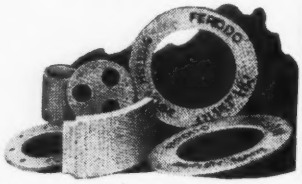

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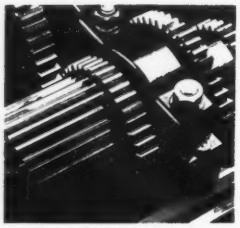

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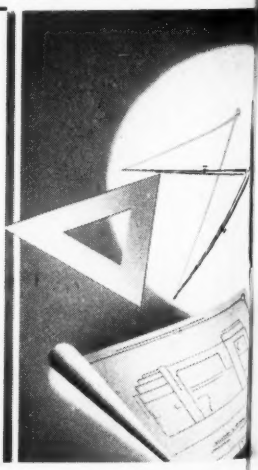

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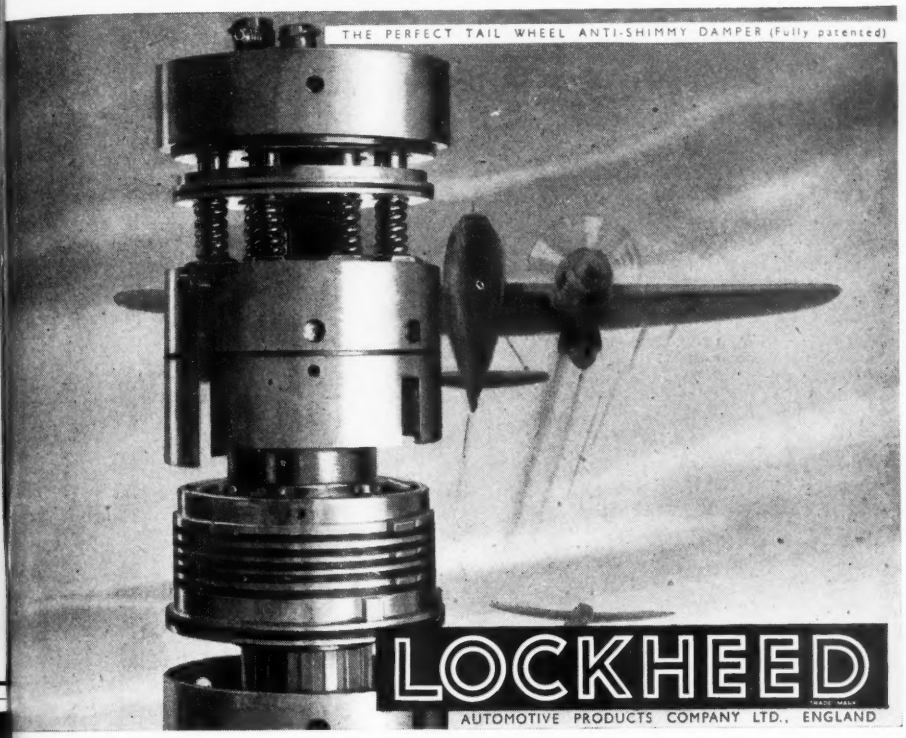

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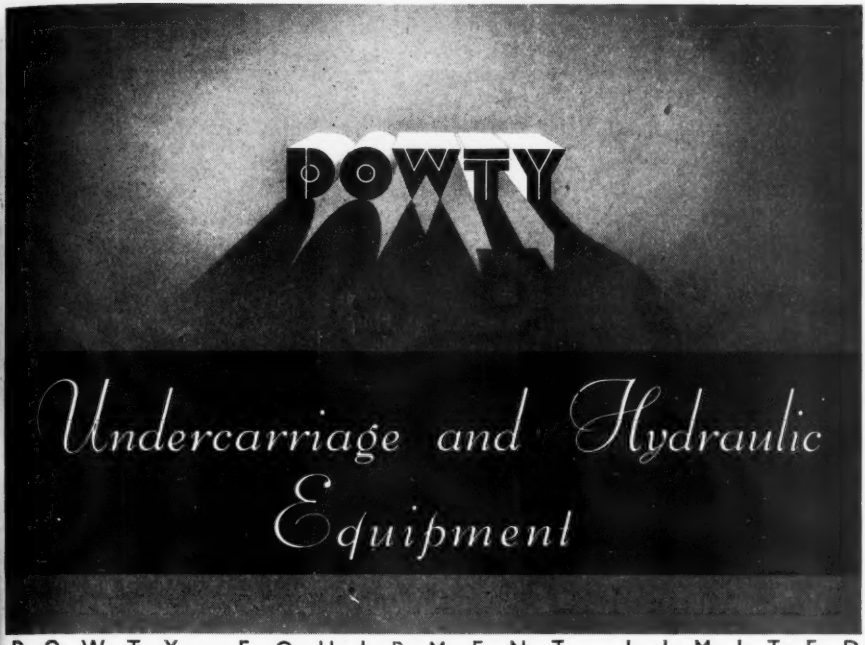

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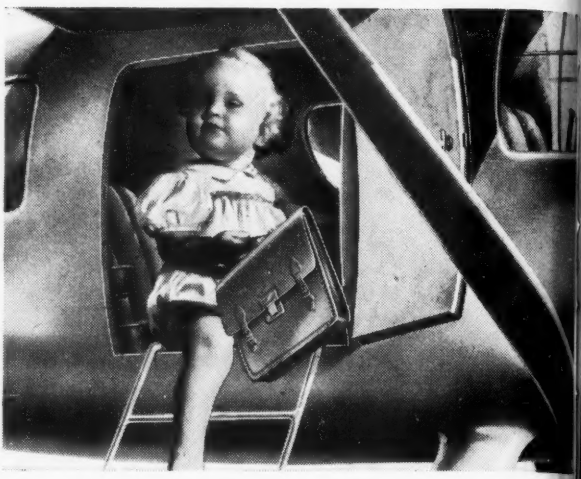

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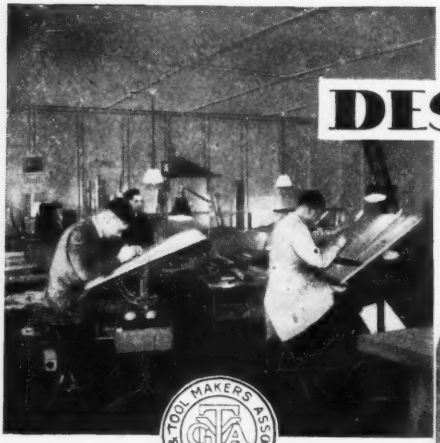

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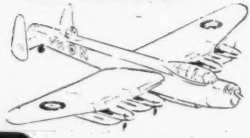

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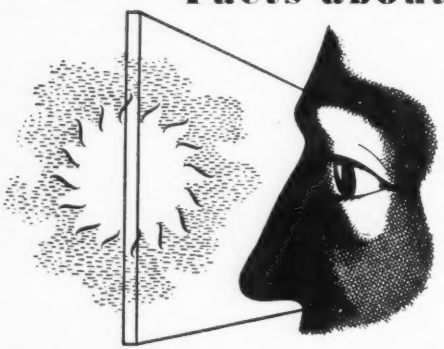

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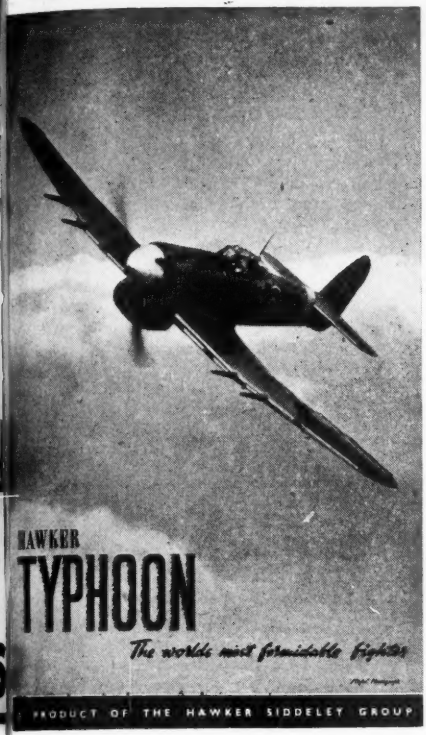

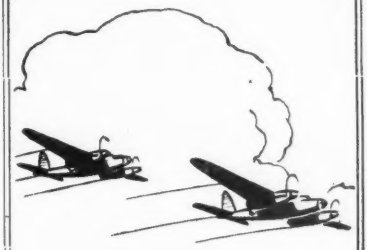

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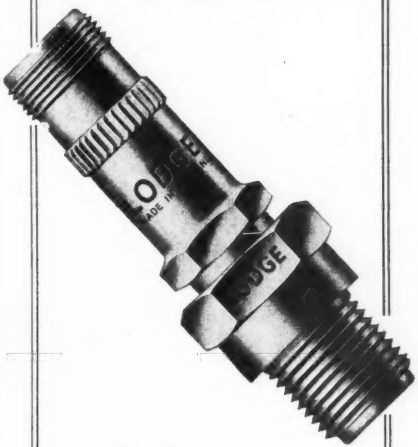

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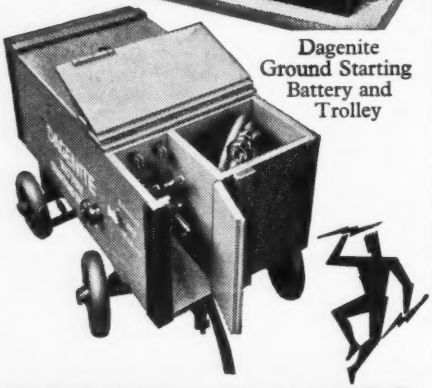

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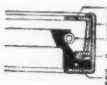

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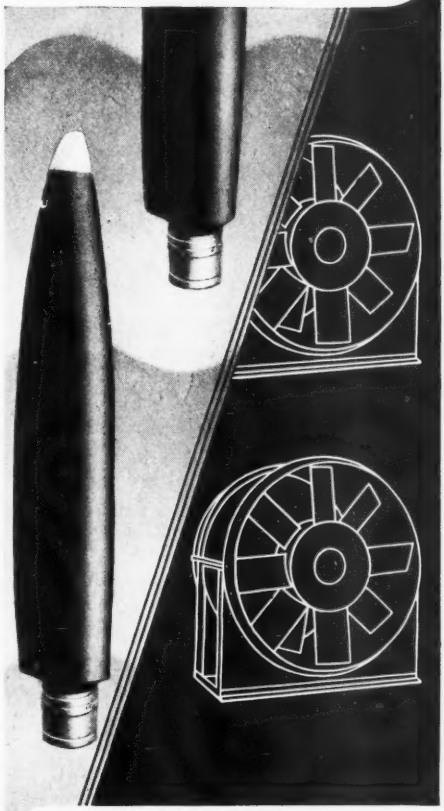

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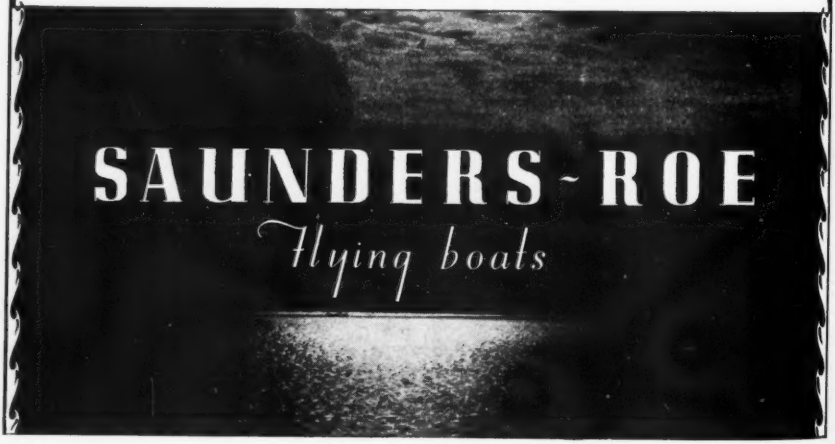

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OF
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THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY *was founded in* 1897 *in succession to the* ANNUAL REPORTS.

For the opinions expressed in Papers that are signed or initialled the authors alone are responsible. None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless such is definitely stated to be the case.

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Edited by Lt.-Col. W. Lockwood Marsh, O.B.E., F.R.Ae.S., M.S.A.E., F.I.Ae.S.

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PRINCIPAL JULY CONTENTS:

The I.Ae.S. Annual Meeting (Concluded). A. Klemin.
The Utilization of Exhaust Thrust. N. Y. Litvinov.
Estimation of Aeroplane Ceilings. J. F. Foss.
Roots of Frequency Equations. R. G. Manley.
Screws and Airscrews. T. H. Day.
Aero-Engine Production. E. Fairbrother.

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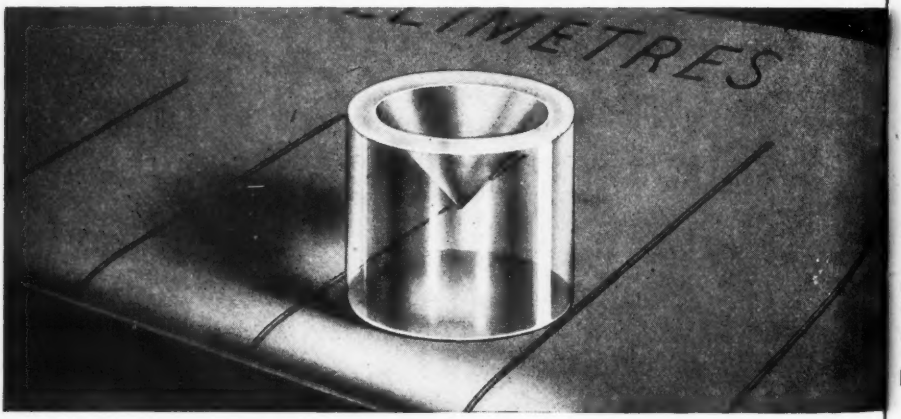

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THE ROYAL AERONAUTICAL SOCIETY
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MONTHLY NOTICES

JULY, 1944.

Birthday Honours.

The following members received honours in the recent Birthday Honours List:—

K.B.—

J. S. Buchanan, C.B.E., A.M.I.M.E., F.R.Ae.S.
Air Commodore J. A. Chamier, C.B., C.M.G., D.S.O., O.B.E., A.F.R.Ae.S.

K.C.B. (Military Division)—

Air Marshal R. S. Sorley, C.B., O.B.E., D.S.C., D.F.C., A.F.R.Ae.S.

C.B. (Military Division)—

Air Vice Marshal D. C. T. Bennett, C.B.E., D.S.O., F.R.Ae.S.
Air Vice Marshal E. W. Stedman, O.B.E., A.R.C.Sc., Wh.Sc., F.R.Ae.S.

C.B. (Civil Division)—

Air Commodore V. S. Brown, O.B.E., M.A., F.R.Ae.S.

C.B.E. (Civil Division)—

E. F. Relf, F.R.S., A.R.C.Sc., F.R.Ae.S.

M.B.E. (Civil Division)—

C. H. Cunniffe.
Squadron Leader J. D. Haddon, F.R.Ae.S.
F. J. V. Holmes, A.F.R.Ae.S.

O.B.E. (Civil Division)—

Dr. A. G. Pugsley, F.R.Ae.S.

Graduates' and Students' Section.

A Meeting of the Graduates' and Students' Section will be held in the Library of the Society at 7.30 p.m. on Monday, July 24th, 1944, when Mr. L. P. Coombes, F.R.Ae.S., will give a talk on Aeronautical Developments in Australia. The lecture will be illustrated by a film and will be followed by a discussion.

Durand's "Aerodynamic Theory."

A further limited supply of copies of the reprinted volumes of Durand's "Aerodynamic Theory" will shortly be available and those members desiring copies should make early application to the Secretary. The cost of the set of six volumes is £7 10s., but should not be sent with the application for copies.

Journals.

The Secretary would very much appreciate it if those members who have finished with their Journals issued in 1944 would return them as the stocks in the Society's possession are very low.

Acknowledgments.

The Council acknowledge with thanks the gift of Journals from Mr. D. J. Davidson, Squadron Commander J. Bird and Mrs. Walker-Sinclair.

Luton Branch.

The following lecture has been arranged by the Luton Branch of the Society:—

Friday, July 7th, 1944, at 7.15 p.m.—Lecture on "Problems of Undercarriage Retraction," by Mr. H. G. Conway.

Election of Members.

The following members have recently been elected:—

Associate Fellows.—Edward Dundonald Ayre, Arthur Wickman Coney, Norman Jesse Flood (from Graduate), Peter William Howes, Mikolaj Kaczanowski, Mieczyslaw Lewandowski, Duncan Douglas Lindsay, Donald Macfarlane, Frederick George Molony (from Associate), George Edward Otter (from Graduate), John Reginald Quertier, Arthur Joseph Audoen Quirke, Arthur Ronald Short, Henryk Sliwinski, Alexander Paul Crayston Webster, William James Williams (from Associate).

Associates.—Edward Armistead, John Wilmot Bateman, Frank Robert Blasdale, Marcus Baxter Booth, Derek Alan Lyn Carlisle, John Raymond Cross, William Samuel Cook, Herbert Austen Davenall, Philip George Davis, Geoffrey Devas Everington, Walter Francis Fowle, Geoffrey Temple Gray, Eric Stanley Greenwood, Arthur James Henderson, William Henry Hopkin, Thomas Kearns, William Henry King, Frederick Mack, Eric Mangham, Henry Wallis Noble, William Glynn Petre, Richard S. Randolph, Henry John Ridgewell, John Cyril Roberts, Ernest Owen Scarr, Charles Smith, Joseph Swinburn, Frederick Charles Watson, Cyril Claude Wood, Lewis Louis Wozencroft.

Graduates.—Alan Farrer Barker (from Student), John Edward Curtis, Geoffrey Gould (from Student), Douglas William Holder, Leonard Joseph Hughes, Marian Markowicz, John Parkinson (from Student), Ernest Edward Smith.

Students.—George Gilmour Clark, Paul Alfred Holloway Fordham, Alexander Kenneth George Gilbertson, Richard Alan Harriss, Derek Edmund Harvey, Alfred Dennis Jackson, Peter Dundonald Jackson, Cyril Robert Milam, Benoyendra Naug, Leonard Arthur Petty, Hedley Derwent Scorer, Kenneth George Sidney Sears, Ronald Alfred Wilton.

Companions.—William Frank Burbidge, Arthur Edward Richard Clark, Walter Cullen, Frank Cassels Dunn, Robert Francis Eatock, Alexandre Siniak.

Correction.

PHYSIOLOGY IN AVIATION. Chalmers L. Gemmill.

Our review last month omitted to state that the above book, published by Messrs. C. C. Thomas, Illinois, U.S.A., is obtainable in England through Messrs. Baillière, Tindall & Cox, price 11/-.

The same applies to "A Bibliography of Aviation Medicine," by E. C. Hoff and J. F. Fulton, reviewed in our issue of February, 1944. (Price 22/6.)

Additions to the Library.

The following books have been added to the Library during June:—

Pamphlets in italics with location reference following in brackets.

Books marked * may not be taken out on loan.

B.a.315.—A.P.1404A. The Hart Aeroplane (Kestrel I.B. Engine). Air Ministry. H.M.S.O. 1935. 2/6.

B.g.136.—British Aircraft (Vol. I). R. A. Saville-Sneath. Penguin Books. 1944. 5/-.

*B.g.137.—*Aircraft Recognition Test Sheets (Plan, Side and Head-On Views for 1st, 2nd and 3rd Class Tests). National Association of Spotters' Clubs.* 1944. (File Case: Folio.)

BB.b.108.—A.P.1208. Airworthiness Handbook for Civil Aircraft. (1932 Ed., reprinted 1934.) Air Ministry. H.M.S.O. 1934. 5/6.

BB.f.49.—Instruments for Flight Research. Smith's Aircraft Instruments Co. Undated. (ca. 1942.)

BB.f.50.—*Smith's "Desynn" System, Handbook No. 1. Smith's Aircraft Instruments Co.* 1942. (PBB.3.a.5.)

D.b.205-208.—*Parliamentary Debates, Official Reports: Vol. 400, Nos. 77 and 78, House of Commons; Vol. 131, Nos. 47 and 48, House of Lords. H.M.S.O.* 1944. 6d. *each.* (Y.20.ii.)

*D.b.209.—*Little-Known Facts about the Scheduled Air Transport Industry. (5th Ed., 1943.) Air Transport Association of America.* 1943. (Folio.)

D.b.210.—*Planned Expansion. C. E. Leasure. (Lecture before the Minneapolis Council of National Aeronautics Board, March 27, 1944; stencil.)* (Y.6.a.38.)

E.d.21.—Calculations from Drawings. F. Holliday. Sir Isaac Pitman & Sons. 1944. 7/6.

E.f.103.—Practical Aircraft Rigging. P. W. Blandford. Hutchinson & Co. 1944. 2/6.

E.g.8.—Elements of Aeroplane Hydraulics. Harold P. Lees. Hutchinson & Co. 1944. 2/6.

*EE.h.12.—Gas Turbines and Jet Propulsion. G. Geoffrey Smith. "Flight" Publishing Co. 1944. 6/-. (3rd Edition.)

*I.e.31.—*Abridged Callendar Steam Tables, Centigrade Units. H. L. and G. S. Callendar. Edward Arnold.* 1934. 1/-. (*3rd Ed.*) (PI.1.11.)

*Q.a.151.—*Aeronautic Americana. (Books and Pamphlets published in America before 1900.) N. H. Randers-Pehrson and A. G. Renstrom. Institute of Aeronautical Sciences.* 1943. (PQ.1.a.11.)

*V.5/50.—Institution of Mechanical Engineers: Proceedings, Vol. 150. July-Dec. 1943.

*X.a.52.—Aircraft Mechanic's Pocket Manual. Joseph A. Ashkouti. Pitman Publishing Corporation, New York. 1942. 5/-.

*X.a.53.—Aircraft Mechanic's Pocket Book. John T. Henshaw. Sir Isaac Pitman & Sons. 1944. 2/6.

*X.c.M.24.—A Glossary of Technical Terms as used in the Metal Industry. (English, French, German, Italian.) Louis Cassier Co., Ltd. 1942. 2/6.

J. LAURENCE PRITCHARD, *Secretary and Editor.*

PROCEEDINGS.

A Meeting of the Royal Aeronautical Society was held on January 22nd, 1944, in the Lecture Theatre of the Institution of Mechanical Engineers, Storey's Gate (by kind permission of the Council of the Institution), when a paper was read by Mr. Eric Mensforth, M.A., M.I.M.E., and Mr. W. E. W. Petter, B.A., A.F.R.Ae.S., entitled "Aspects of the Design and Production of Airframes, with particular reference to their co-ordination and to the reduction of the development period."

THE PRESIDENT, Mr. A. Gouge, F.R.Ae.S., was in the chair.

ASPECTS OF THE DESIGN AND PRODUCTION OF AIRFRAMES WITH PARTICULAR REFERENCE TO THEIR CO-ORDINATION AND TO THE REDUCTION OF THE DEVELOPMENT PERIOD.

ERIC MENSFORTH, M.A., M.I.M.E., and W. E. W. PETTER, B.A., A.F.R.Ae.S.

1. INTRODUCTION.

The title of this paper indicates a very wide subject but no attempt is intended to make any general survey of airframe design and production except insofar as this is necessary to illustrate the problems associated with their co-ordination and the reduction of the development period. This in itself represents a formidable task which cannot be dealt with comprehensively.

The subject is one fundamentally affecting, from a military viewpoint, the capacity of the country within its economic resources to maintain, war strength or war potential and from a civilian viewpoint the country's ability to compete internationally in the field of air transportation.

The object of the paper is to seek to define some of the problems which arise and by stating what are frequently elementary facts, and by giving examples from a particular and necessarily limited experience to promote the publication of other information and to focus attention and discussion upon this.

2. FORM OF PRESENTATION.

It is proposed to:—

Section 3.	State the problem.
Section 4.	Summarise broadly the authors' main conclusions.
Section 5.	Describe the development and constructional stages through which an airframe passes with reference to particular examples and the derivation of an "ideal" programme.
Section 6.	Describe those features of organisation which have a particular bearing on the co-ordination of design and production.
Section 7 and 8.	Describe a number of the main factors which affect co-ordination and the speed of development.

3. STATEMENT OF THE PROBLEM.

Fundamentally the problem facing any aircraft constructing firm is to secure that co-ordination of design and production as will produce the most satisfactory aircraft in the shortest possible time from its original conception. The feature of time is a particularly important one as aeronautical science is advancing extremely rapidly and there must always be a struggle between fundamental aerodynamic or

other design requirements important for technical perfection and finality for actual production. It must be clear that a project well conceived for aerodynamic and operational purposes is bad if its translation into production is unduly costly in time or in labour.

The design of an airframe involves technical problems of great complexity on a scale perhaps unparalleled in any other engineering construction, or indeed in any other human enterprise. The carrying out of the work of design requires a large team of engineers; there are practical limitations to the size of the team, and more particularly it has to be controlled by a limited number of persons so that in the result a necessarily long time is involved. During this long period of design there must often be a balance struck between the value of a particular novelty and the cost in time taken in introducing or learning to introduce the new feature. At all periods there are a number of interacting factors of the design itself and of the production facilities which affect materially the whole enterprise. These factors have to be considered to see in what way they may be co-ordinated.

The problem of reducing the period of design of an airframe is one that becomes increasingly important particularly with the reduction in time that may occur in the development of new prime movers, e.g. those associated with jet propulsion. While it may be accurate to say that over some considerable period it has been possible to design several successive airframes round one engine as this has evolved over a period of up to 10 years, there will increasingly be a necessity for new airframes to be developed to accept basically new engines at fairly rapid intervals.

4. Broad Conclusions.

The experience of the writers, necessarily limited, leads to a number of broad conclusions which are summarised below. These and indeed the whole subject matter of the paper have application to all metal aircraft of medium size designed for military purposes. There will be differences when smaller or larger aircraft are considered and when wooden construction is adopted, but it is believed that many of the factors and arguments will have common application.

4.1 *Organisation.* The most effective airframe design and production will be obtained from a compact and closely knit organisation where design is carried out in a production atmosphere but at the same time the production people are sympathetic to, and closely in touch with, design problems. Increase in size of the organisation beyond a reasonable optimum will achieve little, but an inability to reach this optimum size will be costly.

4.2 *Development period.* The development period of an aircraft has commonly been of the order four years or more; theoretical study indicates that under the most ideal conditions this might be reduced to two years; these conditions would never be achieved in practice; it is perhaps reasonable to aim as a target at a time of 2½ years.

The achievement of this figure requires a maximum concentration of effort, and will also presuppose a freedom from major technical difficulties which can by no means be guaranteed in so complex an engineering project as a new aircraft.

4.3 To attain a minimum development time the following conditions must be fulfilled:—

4.3.1 The period during which the specification is clarified and defined must be reduced to about three months, as has already been shown recently to be possible.

4.3.2 The prototype must be ordered as soon as clarity of specification is reached.

4.3.3 A production order or at least authorisation for production tooling and material ordering must be given within six months of the ordering of the prototype; this means that heavy commitments must be made before the experimental aircraft is flown.

4.4 There must be a maximum concentration of effort at the design development firm which should under war conditions be working on one major project only at one time. In this connection the natural aspiration for new firms to become design firms must not be allowed to interfere with the national development effort by dissipating the energies of available competent staff who should be concentrated into relatively few strong design offices. This does not mean that there should be only one design for an important aircraft; to safeguard the position in war, and in peace to make competition, two or even more may be reasonable, but even then it is possible that not more, and perhaps less than the present number of design firms can be kept efficiently busy. .

It is important that the design firm should have continuity of development work so that its staff may develop that tradition which will assist in the speedy and accurate solution of new problems.

4.5 Special steps will be necessary within the design organisation which will include:—

4.5.1 A maximum concentration and specialisation of individual efforts so that those generally few persons capable of doing the basic scheming work are relieved of as many routine responsibilities as possible.

4.5.2 An organisation such that very close collaboration exists at all times between the design and draughting sections and works production departments including processing, jig and tool design, and inspection.

4.5.3 The adoption of, and adherence to, a stable system of drawing office standards including the use of a very limited number of raw materials, drawn and extruded sections, standard blanking and lightening hole tools, milling cutters, etc.

4.5.4 The use of lofting methods to develop and define through templates the main aerofoil and other dimensions of the aircraft.

4.5.5 The employment of accurate " mock-ups " for the positioning and detail installation of equipment and services, instead of relying entirely on layout work on the drawing board.

4.5.6 Employment on some straightforward units of sub-contract designers, as for example a portion of a design firm's office who are not at the moment heavily loaded, so as to bring to bear over a relatively short time the biggest possible detailing staff.

4.6 To obtain the most rapid production development there must be separated:

4.6.1 Initial production development which will take place at the basic design firm and use, at least to commence with, limited tooling only to get established quickly relatively small scale production; this will prove drawing and other manufacturing information and at the same time get aircraft into moderate scale operational service rapidly. The firm undertaking initial development will require comparatively more skilled labour and a stronger organisation than that acting as a " daughter " or shadow firm only.

4.6.2 Production extension by elaboration and extension of design firms' original tooling or by the provision of tooling at " daughter " firms or shadow factories; a sufficient time lag must be allowed between this stage and the previous one for the correction of manufacturing information.

The following considerations are also important:—

4.6.3 The scale of tooling employed should not generally be such as to cost more than 5 per cent. of the total airframe price.

Production at normal full output from this tooling should be expected to continue for at least 18 months.

4.6.4 Unnecessarily high peak output, to be maintained for a short time only, should not be specified as in affecting the scale of tooling this adversely affects cost and time of development so that the time of execution of the contract will probably not be reduced.

4.7 The development firm must have a continuing and steady production load for its works; this may be on its own last and fully developed aircraft, or alternatively on the product of another designer where it will then be acting as a daughter firm.

The basic output is essential to build up a reservoir of labour for training of skilled operatives and staff and for the gaining and maintaining of that up to date production experience which is essential if practical and efficient designs are to be made.

Output of this basic aircraft must overlap properly, taking into account likely delays, and not allowing undue optimism to interfere with reasonable estimates, production of a new aircraft.

Two aircraft, in various production stages at one time, with, on occasion, a third in its very early design stage, are required and are all that is necessary for the optimum operation of a basic design firm.

4.8 The method of obtaining continuity and the degree to which it should be obtained will depend upon whether the country is at war or not. In this war aircraft have been found to be required for important tasks a considerable time after they have ceased to be used for first line duties and are nominally obsolescent; subject then only to special raw materials supply circumstances, the maximum utilisation of available man hours must be the criterion during a change-over in type. In arranging for the manufacture of a new type and for the cessation of production of another, reasonably to be expected delays must be considered and that number of the obsolescent aircraft required to maintain continuity of employment boldly ordered and accepted for delivery.

4.9 It is important that public opinion and in particular that of the supply services, should know what length of development period does represent a major and efficient engineering industrial effort so that there may not be an ill-informed demand for something more rapid leading to confusion and inefficiency and perhaps even having important consequences on strategy.

4.10 The industry must have a sufficiently stable outlook to attract good recruits and it must then see that good educational facilities exist and are made available to all who can take advantage of them.

5. Development and Constructional Stages.

In developing a new aircraft a number of stages will be passed through (as defined in text):—

5.1 *Specification.* After issue of the first specification discussion will take place between a limited number of firms and the Ministry over a period of months until a final and compromise specification is reached upon which prototype design work can commence. This stage frequently takes six months or longer, but has been reduced recently. It is suggested that clarity of specification should be achieved within three months of its first issue.

5.2 *Development design.* During this period the necessary basic design work, including research and wind tunnel work, stressing and production of development drawings is carried out; it will last over a year, and will then require a maximum concentration of effort.

During, and following upon the development design period, the actual prototypes are constructed and pre-production work commenced.

5.3 *Production design.* Preparation of production drawings should commence as early as possible after issue of prototype drawings; work on them will continue until the prototypes have been flown and approved.

5.4 *Pre-production work.* As soon as production drawings are available and to a considerable degree even before by working from the prototype drawings, pre-production work, including process planning, material ordering, jig and tool design must be carried out.

5.5 *Flying experience.* During the stage of the experimental flying of the prototypes a number of possible failures which can be corrected, or desirable improvements which are to be incorporated in the final design, will be found.

It is most desirable, however, that intensive flying under service conditions should be carried out very early as this may show other necessary changes. To do this quickly the policy of advancing the construction of, say, the first three production aircraft as rapidly as possible, even if prototype methods of building have to be employed, is to be welcomed and encouraged. The two prototype aircraft which are normally constructed are employed fully for purely technical purposes, and a further three aircraft are the minimum with which intensive service flying trials can be carried out.

5.6 *Initial production.* Initial production will follow the issue of production drawings and completion of pre-production work and this stage will have a time relationship to the design stage which depends essentially on the degree of accuracy and certainty achieved in the issue of design manufacturing information. During this stage a compromise will have to be effected between the amount of tooling and the speed of production of early aircraft. Its function is to get established quickly a relatively small scale production to prove drawings and other manufacturing information and at the same time to get aircraft into moderate scale operational service rapidly. The firm that undertakes such initial production development will require comparatively more skilled labour and a stronger planning and production organisation than those who act as following daughter or shadow firms. This production will be similar to that to be expected in time of peace and naturally is that undertaken by the professional industry in its own basic design factories.

Failure to understand the necessity for supporting this phase and advancing it as much as possible, with in any case a definite time lag of preferably at least six months before the next one is commenced has resulted in very serious output losses in a number of important national projects.

5.7 *Service operation.* This is the ultimate object of the whole development; although the development part may have been kept relatively short up to this time the efforts in achieving this will have been lost unless the aircraft as developed can be kept serviceable and at a high degree of operational efficiency. This means that the aircraft must be easy of maintenance and with the necessary instruction manuals, etc., available, while at the same time there must be an adequate spares and repair service.

5.8 *General.* During the above stages of development it will be clear that the time taken will be materially affected by:—

5.8.1 The degree of novelty of the design, particularly the extent to which it is directly derived or modified from an existing type.

5.8.2 The type and strength of the organisation available for design and production. This is dealt with more particularly in Section 6 below.

5.9 *Extended production.* During this stage production will be extended by the elaboration and extension of the design firms' original tooling or by the provision of tooling at the daughter firms or shadow factories.

5.10 *Development period.* The Table, Fig. 1, shows some of the times actually taken on a comparable basis for the development of a number of recent aircraft; it illustrates the effect of some of the factors which are under discussion. A study of it indicates very roughly what might be considered under existing circumstances to be the minimum possible or " ideal " design period; from this it is argued that the minimum likely development period, defined as the time taken from the Ministry of Aircraft Production indicating the requirements of the service for a new type to the delivery of the first operational aircraft will not be less than 2½ years. Claims for shorter times are frequently heard of particularly in the U.S.A., and to the degree that a very much larger amount of man power may

be capable of effective applications may have been achieved; the writers have no first hand experience of these.

6. ORGANISATION.

6.1 *General.* It is necessary to consider briefly the aircraft constructor's organisation as a whole as this must be viewed as a single entity.

TABLE OF DEVELOPMENT PERIODS.
TIME TAKEN IN MONTHS FROM COMMENCEMENT.

Whether Novel or Derivative Type of Aircraft	Aircraft A.1. Novel	Aircraft B.1. Novel	Aircraft C.1. Novel	Aircraft D.1. Derivative	Aircraft E.1. Derivative	Theoretical Best.
Type and All-up Weight	Hurricane Single Engine Single Seat Fighter 6,000 lb.	Lysander Single Engine Two-Seater Reconnaissance 6,000 lb.	Whirlwind Twin Engine Single Seat Fighter 10,000 lb.	Typhoon Single Engine Single Seat Fighter 10,000 lb.	Welkin Twin Engine Fighter	Single Seat Fighter
Specification Period						
1. Months start before design tendered	−8	−3	−4	−3	−2	−3
2. Design first tendered to Ministry. Clear for work to commence ...	0	0	0	0	0	0
3. Prototype drawings started in D.O. ...	−3	4	5	7	1	1
4. Mock-up conference ...	4	—	11	17	5	3
5. Prototype aircraft ordered	5	4	5	13	1	0
Development Design Period						
6. Prototype drawing issue started	1	7	8	9	4	4
7. 1st Prot. 1st Flight ...	14	16	30	31	22	16
2nd Prot. 1st Flight ...	—		35	—	24	
Production Development Period						
8. Production order rec. from Ministry ...	21	17	32	27	8	3
9. Product. dwg. started in D.O.	18	—	27	17	8	4
10. Product. dwg. issue started	21	—	29	26	11	7
11. Process planning started	21	—	31	27	9	5
12. 1st Prod. aircraft, 1st Flight	37	36	49	46	28	21

FIG. 1.

Such an organisation will be under the leadership of a chief executive, probably managing director, with, associated with him, colleagues in charge of the main functional divisions of (see Fig. 2):—

(*a*) Engineering (Technical Director)
(*b*) Production (Works Director)
(*c*) Inspection (Chief Inspector)
(*d*) Finance (Secretary)
(*e*) Commercial (Contracts Officer)

GENERAL FACTORY ORGANISATION CHART.

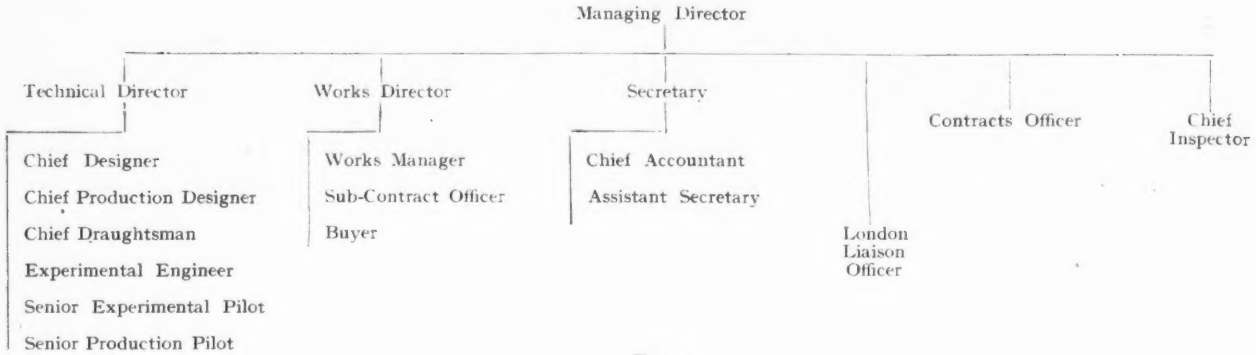


FIG. 2.

DESIGN ORGANISATION CHART (ORIGINAL).

FIG. 3.

These divisions are generally self explanatory; for the purpose of this paper it will be necessary only to consider in more detail those of engineering, production and inspection; this is done below.

6.2 *Engineering organisation.*

6.2.1 *General.* The object of design is the creation of a product which is initially satisfactory to the customer and which is maintained so in spite of the varying needs and uses to which the product is put throughout its useful life. Quite obviously, however, the product selected must for the good of the organisation and the ultimate benefit of the customer, be one which makes the fullest use of the available resources of the company, particularly in the matter of previous experience and production facilities.

Only a small proportion of the design technical staff is required to be creative in function. Around the essential creative core is grouped a larger body of those aided by common sense, training, and experience, to assist in transmitting the creative ideas into practical realities, as well as in handling the large number of problems which are not in themselves novel and which are capable of treatment by known methods.

Certain conditions are essential for the proper functioning of this somewhat complex organisation, the most important of which is that it should function in a liberal and enlightened atmosphere free from the exercise of undue pressure or restraint. Technical and other design decisions require to be reached by the exercise of cool thought and reasoned discussion. Almost as important is the necessity for the stimulus of contact with other engineers and designers working perhaps on allied but differing problems, and to this end a certain amount of time must be spent by technical staff on visits, conversations with colleagues, study of technical papers, and all those allied operations which provide the raw material from which creative thought springs. It is an interesting corollary to this that aeronautics with its exacting demands on mechanical, electrical, metallurgical and other skills will probably be the major stimulant to, or irritant leading to, engineering development during the next one or two decades.

Since these thought processes are largely the development and synthesis of past and present experience and activity, the best results will be achieved if there is a general consistency in the policy and type of development undertaken. To summarise, the ingredients of the atmosphere in which the best work will be done are creativeness, common sense, realism, consistency, an intelligent interest and freedom from improper restraint.

6.2.2 *Recruitment of staff.* Enough has already been said to show that the component parts of a design team will be of a very varying character; the majority, that is those who will exercise commonsense and the qualities of trained and analytical thought, can be and are reared successfully within the framework of a good apprentice scheme; if this is extended to include the training of students of matriculation standard in the workshop, by continuation classes in mathematics, etc., and design office apprenticeship.

While a certain number of creative designers may be found in those trained in this way, the over-insistence upon this source of recruitment as the only one will leave an insufficient number of creative designers available and wider sources of supply must be tapped—ones which do not necessarily place a bar to those of unusual education, training or character. During the war period the authors' company has, for instance, recruited and obtained excellent work from Polish and other refugee engineers who had come to this country. The opinion is further held that from those who have obtained a "classical" school and university education with its very wide cultural background, and its wide, if somewhat superficial, knowledge of other branches of engineering, it is possible to select a high proportion of creative engineers, and for this reason, as well as many others, a proportion of the annual recruitment should if

possible—and unfortunately generally it is not during the war—be made from this class of person.

6.2.3 *Organisation.* During the development and production of the Lysander, and the design and building of the Whirlwind, the writers' Technical Organisation followed the normal pattern still widely employed; this certainly functioned well so long as the organisation was comparatively small. The form of this was shown on Fig. 3. With a widening scope of activities, however, this arrangement was found to have certain disadvantages, principally:—

(*a*) The Chief Designer was of necessity pre-occupied with new design work and there was a corresponding tendency for the firm to give insufficient attention to modifications to meet the customer's latest needs and requirements.

(*b*) Conversely troubles, often comparatively minor, in the production design or in service, would lead to the Chief Designer and his immediate staff having to drop their new work, which was frequently of much greater real importance.

(*c*) The building and testing of the Whirlwind brought out clearly the need for a very strong testing and research staff, one in particular which was capable of trying out by tests in advance unusual features of the design and also those items of bought-out equipment, such as hydraulic gear, controls, etc., upon the satisfactory functioning of which the airframe constructor is so dependent. It was evident that a senior member of the staff was required full time to watch over these activities.

(*d*) The Chief Draughtsman, although responsible, was not always in the position to obtain the necessary proper allocation of staff for dealing with modifications and the preparation of the essential spares, books, maintenance and other service manuals.

It was at this time that an article in the *S.E.A. Journal* for December, 1938, in which Cranford and Collins, of the Chevrolet Company, described their organisation, was seen and suggested a new approach to the problem. The arrangement described seemed to fit so well the needs of the engineering organisation of an Air Ministry approved airframe manufacturer that it was adopted at Westland; it was adapted slightly to suit the requirements of an airframe firm, as for instance in the matter of inclusion of senior piloting personnel as one of the main groups for which the Chief Engineer or Technical Department must be responsible. This organisation has obtained for the last five years, and no changes whatever in the headings or their main responsibilities have been found necessary. It is as shown in Fig. 4; the functions of most of the sections shown in the organisation chart are obvious, but the following notes will assist in defining their scope.

Development design. This section is responsible for all work from the initiation of the original schemes submitted to the customer, i.e. M.A.P., up to the stage of the acceptance of the prototype aircraft. It also controls the Stress Office, whose approval of all designs from all sections is required, whether new or amended. In passing it should be mentioned that every reissued drawing is sent to the Stress Office for approval, although it is believed this is not the general practice of the industry; it is felt, however, to be essential, particularly as alterations are sometimes carried out by less experienced members of the staff. Through the Stress Office the Chief Designer is thus able to ensure that the strength and safety of the aircraft is maintained throughout the life of the product.

Production design. This section is responsible for the preparation of all drawings in production form and assumes complete responsibility from the time of the prototype acceptance. In the event of an order off the board the production design section will take over drawings, schedule them, and

DESIGN ORGANISATION CHART (CURRENT).

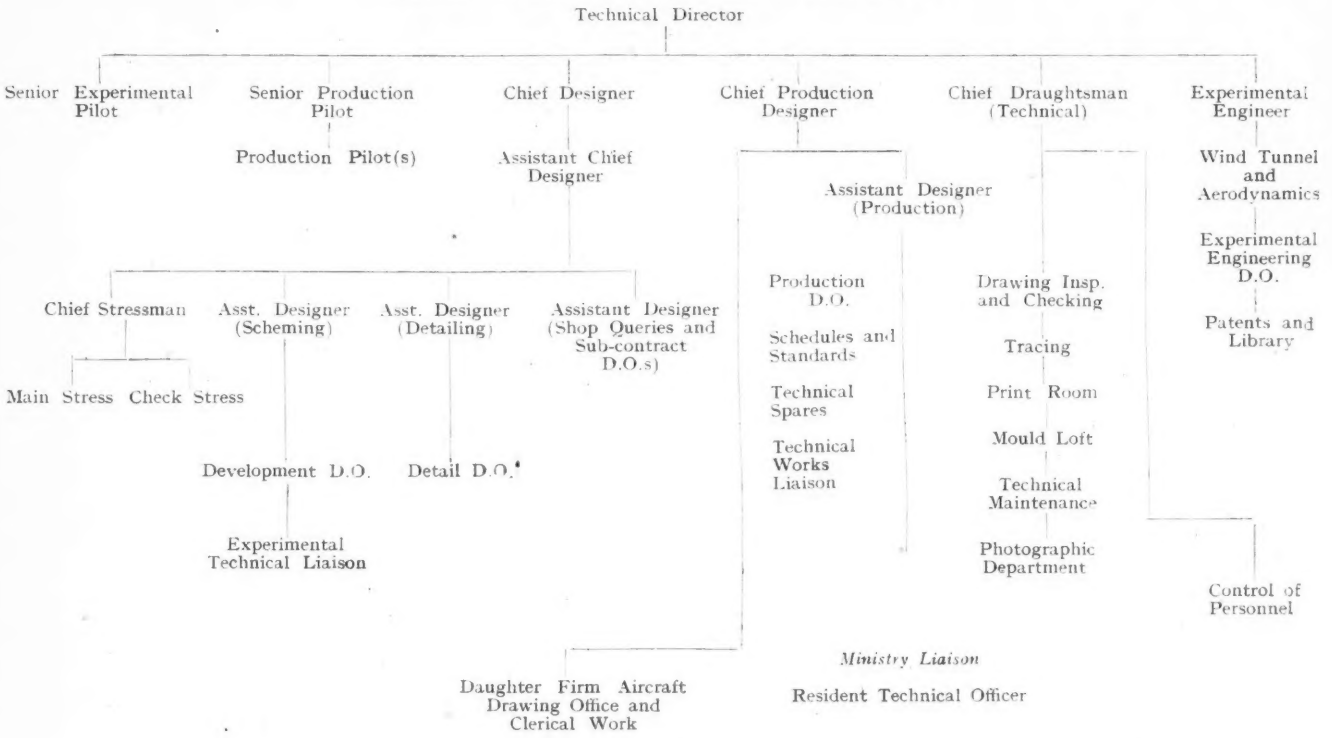


FIG. 4.

re-issue for production on a production issue number very shortly after their original issue for the prototype. Thereafter production design control all drawings in current production use; they carry out alteration of these drawings as required for production and modification purposes, except in the case of very extensive modifications, in which case these are referred back to development design to develop a satisfactory trial installation. Just as production design drawings are passed through the stress for checking, so all development drawings, even those for prototype or trial installation only, pass through the standards section of production design, so that the production designers' function of interpreting manufacturing requirements, maintaining the minimum of difference in the types and kinds of materials used, etc., may be able to operate. The Chief Production Designer and his staff deal with all manufacturing queries which thus disturb the Chief Designer and development design staff very little. This is an arrangement appreciated by the production department of the works who have, in effect, a special section of the design office, whose duty is largely to assist them in many detail, but important, ways to achieve early and cheap production on the current product and to ensure that those factors which will ensure desirable characteristics in a new product, are maintained continuously before the creative designers.

Naturally much of the work of co-ordination between design and production depends on the satisfactory functioning of the production design section.

Experimental engineering. This section is responsible for aerodynamic and wind tunnel work and for the development and testing of special processes and applications. In special cases it will mock up and test complete working models of proposed novel designs and will then criticise and improve them in detail while also watching for any special manufacturing or inspection needs of the product. In this way this section serves a very useful purpose not only in the early design stages but in helping to overcome difficulties in production in such matters as maintenance of satisfactory controls or mechanisms.

In general this section is advisory rather than executive but for certain specialist problems designs may be fully worked out and detailed by them; an example handled in this way is the Westland electric remote control operating unit. Drawings for such items by the Experimental Engineering Section are transferred to the Production Design Sections for production issue, who thereafter deal with all drawing queries.

Other examples of work recently performed are the approval and testing of tank sealing compounds, organisation of full scale tests, determination of deflector plate thicknesses required for the prevention of bullet penetration, testing of proprietary mechanical controls, representing those things requiring testing or the overcoming of special practical engineering problems.

Naturally this section is located near the works and test house. The subdivision of work is broadly that tests of an experimental or early production character are carried out under the ægis of the Experimental Engineer, with routine production testing the responsibility of the Chief Inspector who is thus in a position to obtain the assistance of the experimental staff if special or unforeseen difficulties arise.

Chief Draughtsman. The Chief Draughtsman is in fact an office manager responsible for the engagement and control of all staff. In the modern technical office in which the maximum clerical dilution is introduced to spread the necessarily limited engineers effort over as wide a field as possible, this represents an important post. It includes the control of a large number of Drawing Office services and staff and services such as tracing, print room, mould loft; in fact many of the incidental but important aids to co-ordination between design and production operate through sections controlled by the Chief Draughtsman.

PRODUCTION DEPARTMENT ORGANISATION CHART.

Works Manager

PRODUCTION DEPARTMENT ORGANISATION CHART.

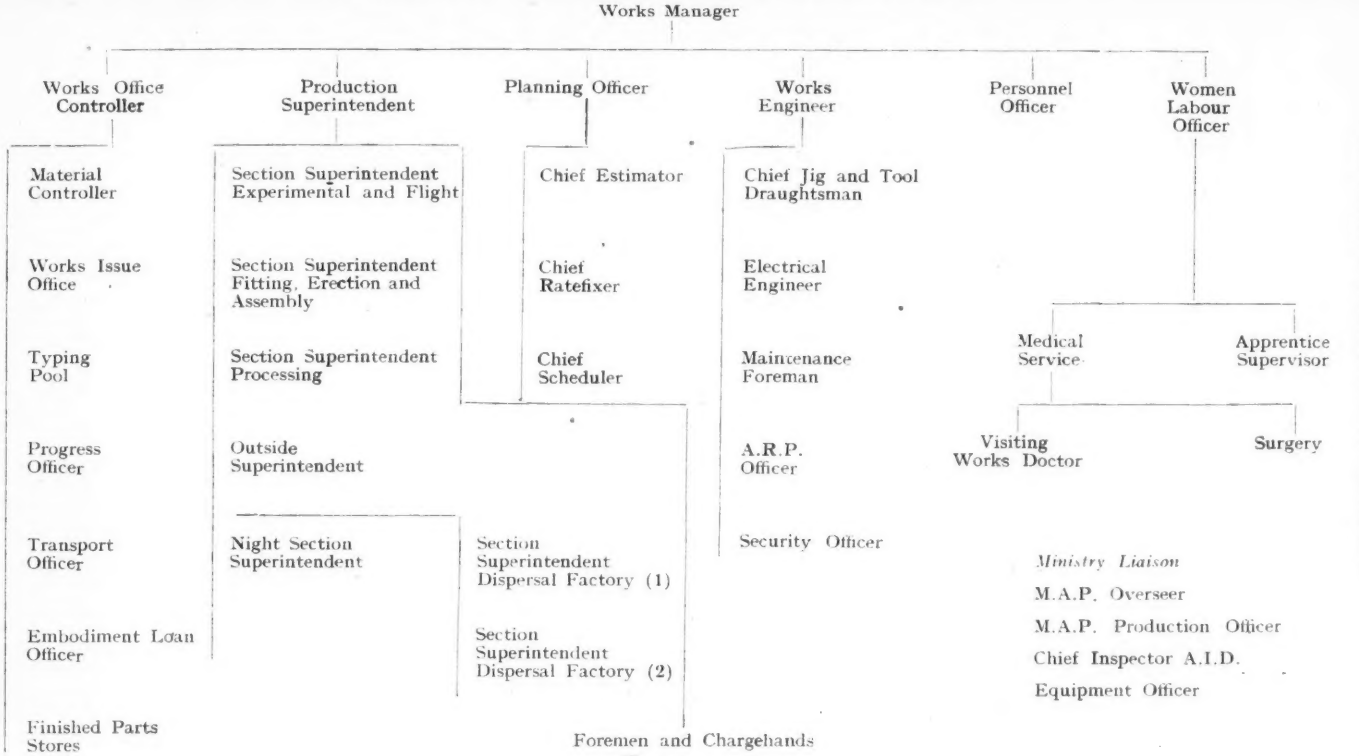


FIG. 5.

6.3 *Production organisation.* The magnitude of the task undertaken in the designing of a new aeroplane is equalled by the effort necessary to produce prototypes and to put the proved machine into production. The necessary complement of a strong design organisation is a strong production organisation capable of rapidly handling the manufacturing information as it is issued by the Design Office; this means an adequate number of trained and skilled people in the actual shops, including machine shop, experimental shop, tool room and inspection, and in the offices on processing, jig and tool design, material procurement and progressing.

The production organisation will embrace the following functional duties, the various departmental heads reporting to the chief works executive as indicated on the typical organisation chart shown in Fig. 5.

6.3.1 *Pre-production.* This embraces the complete preparation of manufacturing information and facilities based on a study of the design drawings. The departments concerned will have a high proportion of engineers and will probably be divided into:—

(*a*) Process planning.
(*b*) Jig and tool design.
(*c*) Labour estimating.
(*d*) Material allocation.

6.3.2 *Materials.* These departments will be responsible for the procurement of materials and for their control throughout the manufacturing processes including their custody at work-in-progress stages; departmentally they will include:—

(*a*) Buying.
(*b*) Stores control.
(*c*) Embodiment loan supply.

6.3.3 *Employment.* This department will be under the charge of a senior person, e.g. Personnel Officer, who will be responsible for all matters of principle in the handling of staff or clock labour, liaison with the Ministry of Labour, maintenance of records, engagement and dismissals, welfare, etc.

6.3.4 *Manufacturing facilities.* This department will be under the control of a Works Engineer responsible for the maintenance of factory services such as heating, lighting, etc., and for the obtaining of all manufacturing facilities; it may also control the tool room.

6.3.5 *Production control.* This includes the preparation of, and adherence to, production programmes.

6.3.6 *Manufacturing.* This embraces all the actual production operations, split into:—

(*a*) Feeder, e.g. press, machine and detail.
(*b*) Sub-assembly.
(*c*) Main assembly.
(*d*) Final erection.
(*e*) Flight and test.
(*f*) Experimental shop.

Each of these will be under the charge of a Superintendent who will be responsible to the Works Manager through a Production Superintendent. In the event of there being any great element of factory dispersal, and perhaps duplication of departments, for wartime reasons, then it may be convenient to have a deputy to the Production Superintendent particularly responsible for the co-ordination of the dispersal units.

6.3.6 *Control of Experimental Shop.* The control character and organisation of the experimental shop is of great importance as affecting fundamentally the co-ordination of design and ultimate production. As indicated above it should be a part of the manufacturing function, but its control should be under a Superintendent of equal seniority to those in charge of

other production sections of the factory. It is important that the experimental shop should be under production control, but enterprise and willingness to appreciate the need for new ideas and methods is essential; these methods are often fundamental to the conception of the design (e.g. skinning sequence). While willing and capable of carrying out prototype construction with a minimum of tooling it must be able to criticise at a very early stage features of the design likely to cause difficulty in later production, e.g. parts necessitating an undue use of skilled labour, rivets that are inaccessible, parts likely to have excessive scrap on them or those unsuited to the company's production facilities.

The experimental shop should be as independent as possible of the production departments for its manufacturing capacity and quite definitely should not be viewed as a place where urgent production shortages may be made good. This will best be arranged by allowing a very adequate space for the experimental shop itself with its own facilities for inspection, stores, etc., the whole to be in close proximity to the design office and loft floor, but to obtain both labour and machine tools, other than the permanent strong nucleus under the very fluctuating load conditions which obtain in the average experimental programme by allocating these definitely for particular periods to the control of the Experimental Superintendent, basing this on a carefully planned budget.

6.4 *Inspection.* The inspection department responsible for the control of quality of the aircraft in production should report directly to the General Manager or Managing Director. This department, with the test pilots, is really charged with the responsibility on behalf of the firm of seeing that the customer's requirements are met and that his interests are watched. From this point of view, while it is not essential, it is convenient to have the servicing engineers who assist in the handling of site troubles on service aircraft report to one or other of these departments so that they may become aware most directly of service troubles on the aircraft and see that effective measures are taken to eradicate them.

It is essential that the inspection department keep very closely in touch with design and production at all stages including the earliest project period; the Chief Inspector should be able to foresee service repair and maintenance difficulties and guide the design and production organisation so that they may be avoided. In this connection it has been found convenient to station a permanent inspection representative in the jig and tool office as a liaison officer.

7. Co-ordination.

7.1 *General.* Fundamentally the obtaining of close co-ordination between the different functional units concerned in the design and development of an aircraft will result from the soundness of the organisation. The following, however, are particular aspects which have been found useful in practice.

7.2 *Liaison with customer.* The design departments carry a great production responsibility in that they are the channels through which requests for change from the customer are received, and indeed they greatly influence, even if they do not finally decide, the effect which such changes will have on production.

It is absolutely essential that the designers in discussing alterations should bear in mind the need to disturb production at relatively infrequent intervals, and in fact do everything possible to simplify the production programme. If this method is adopted, close and energetic attention can be given both in design and manufacture to those changes which really are necessary, particularly where possible grouping a number together to occur simultaneously. It must, however, always be remembered that the ultimate criterion is quality and not quantity in military aircraft; this was demonstrated in the Battle of Britain.

7.3 *Initial design liaison.* It has been found convenient as soon as a new project is contemplated to circulate a brief description of it to all functional

sections of the organisation with the request that during the next month or six weeks they should record and send to the Chief Designer any points which they consider from experience on the last project should have particular attention. These suitably codefied have been found to be helpful.

As soon as any draughting work commences it will save time and later effort to have initially a fortnightly, and later a weekly, meeting to discuss at the highest organisation level the main design features, with particular reference to production. This can best be secured by arranging that the Chief Designer or Technical Director shall be responsible for seeing that during scheming, drawings not absolutely agreed by the liaison arrangements dealt with below at a less senior level should be brought up to a meeting held under the chairmanship of the Managing Director at which there will be present the departmental heads of design, production and inspection. It has been found that such regular discussion maintains a clear position, avoids later departmental recriminations, and generally speeds up the issue of satisfactory design information.

7.4 *Internal design liaison.* Regular routine meetings will of course take place of the various sections of the design departments under the chairmanship of the Technical Director.

7.5 *Basic design and production liaison.* Joint meetings between development and production design chiefs, with representatives present of the experimental shop, inspection, processing and jig and tool offices, should take place regularly during the working out of a new design. At this stage development design will place on the table their schemes before they are detailed, and describe them in order that those concerned with manufacture may appreciate the problems involved and have the opportunity of advising whether, in their opinion, the solution proposed is one which will be satisfactory. The value of these meetings is particularly that general trends and principles are worked out which influence much more than the small fraction of design which can be discussed. Sound production design is, and must remain, the function of those who alone can give the time and attention necessary to all that detail which makes or mars the aeroplane, i.e. to the designers themselves, but they are greatly assisted in carrying out their task if trends and preferences are indicated at meetings of this kind.

Throughout the development stage the drawings are scrutinised by the Chief Production Designer since he will largely be responsible for the design when this is released for production. He is naturally concerned to see that he receives it in a sound and workmanlike condition, and through his schedule and standards section he therefore controls the design with a view to assisting co-ordination with the works in production.

Once production commences regular co-ordination continues between the Chief Production Designer and the various manufacturing departments. The Chief Production Designer attends production meetings where such thorny problems as the introduction of modifications or requests for re-design are raised and usually dealt with on the spot. During the later production life, when the type is actually in use in the squadrons, the Chief Production Designer is in close touch with the Service engineers, where his extensive knowledge of the past history of the type enables him to mix in the right degree willingness to change, when really necessary, with the maintenance of a firm line when some essential feature of the design is at stake. He is able to draw extensively on the services of the experimental engineering section in overcoming servicing difficulties, in carrying out special tests, etc.

Particularly under conditions of dispersal a strong and competent design liaison force in the factory is essential to assist in interpreting drawings, to ensure that these do in fact produce a satisfactory article, and to suggest, discuss, and agree amendments to the design where necessary. Under dispersal conditions the liaison groups have been organised as separate units within the development

and production design offices. Each query is written out on a separate note and answered by the queries section at the design office, who are responsible for keeping down the unanswered queries to the very minimum. In the case of one design, no less than 3,500 prototype queries have been submitted in writing in this way and in a great majority of cases amended drawings were issued; the maximum number of queries awaiting answer at any one time was, however, only 87. In this way up to date drawings are maintained and the system has indeed worked so well that it is being considered whether it should be retained even after dispersal has ceased. By bringing in a third party the very natural disinclination of the original designer to alter his drawing is mitigated and although he is normally consulted he is no longer in the position to prevent an alteration if an unbiased third party considers it necessary.

7.6 *Works Routine Liaison.*

7.6.1 *Prototype construction.* A regular weekly meeting should be held, preferably in the experimental shop with design and production representatives present, at which any hold-ups, design difficulties and the prototype constructional position is reviewed.

7.6.2 *Production.* At an early stage the position on production of the new project should be considered at the weekly works production meetings; this will commence with a reference only to processing, tooling, and material procurement, but will in due course extend to actual shop progress.

7.6.3 *General.* As a new development project relies essentially for its success on the enthusiasm of all concerned in the organisation it is important that as much information as to its genesis and progress as security measures may permit should be made available to all the members of the organisation, both staff and workpeople. This can best be done through the medium of staff and works committees including the latter, particularly the Joint Production Advisory and Consultative Committee.

8. Factors Affecting Rapidity of Development.

8.1 *Methods of draughting.* Obviously the type of drawing presented depends upon the likelihood of production following a prototype. For the last eight years it has been the Westland policy to assume that each prototype will go into production and to endeavour from the start to produce designs which are suitable for production. This policy entails the most careful choice of prototype in conjunction with the M.A.P. and it may be that some revision might be required in the post-war years if experimental work not necessarily followed by production were to become one of the main activities of the industry. During the present phase, however, this policy has been amply rewarded by results, and on the latest fighter it has been carried to its logical conclusion, namely, that even prototype drawings have been produced from the outset in production form, i.e. in the form of assemblies, sub-assemblies, and individual detail drawings for every separate part. Drawings prepared in this way, although still passed through the production design office, in general only require to be scheduled and to have the issue number raised to that corresponding to the first production issue, before being released for full production. Quite frequently this was done within a week of the first prototype issue, although when possible the production issue was held up until drawings had been worked to for prototype, in order that subsequent alterations might be avoided as far as possible.

Using this approach the amount of direct draughting time for a given structure weight of aircraft could be reasonably estimated, as also the number of drawings which will be produced per man. These figures may appear to be high as although the aircraft constructor is only, generally speaking, directly responsible for the structure weight, he has, in fact, to instal the power plants and the

equipment, and these items account for between 30 per cent. and 40 per cent. of the total design time.

The figures of man-months could be reduced to little more than a third if drawings of an experimental type only were produced. The cost and time taken, however, would not be very greatly affected as the limitation would remain that of the number of senior engineering staff available who could be employed on the job. Under conditions of issuing experimental drawings a scheme design as now produced by the designers would constitute the working drawings instead of its going through an intermediate stage of full detailing and expansion, a process which is now removed from the direct responsibility of the engineers as already described.

Drawings produced in this way would not be suitable for large scale tooling and production and it is very doubtful whether the taking of such a short cut is really an economy except under very special conditions; a much heavier demand would undoubtedly be thrown on to the works supervision and skilled labour resources.

8.2 *Special forms of drawing.* An attempt has been made to evolve the best form of presentation for each type of design without preconceived notions as to what form this presentation should take. Close examination has not shown any advantage, for instance, in the use of photography for this purpose although it was thought at one time that for elaborate installations such as that of water or hydraulic systems photographic " drawings " might be useful. It was found, however, that so much that was unnecessary and irrelevant appeared that special perspective drawings were much to be preferred. As an example of the method employed for such " system " drawings—always a problem—a hydraulic system has been used. This is completely covered by the following:—

(*a*) A diagram, which is divided up into separate zones corresponding to that part of the equipment installed in each of the main identifiable parts of the machine.

(*b*) A Schematic G.A. of each of these parts. When not very elaborate this takes the form of a normal three-view general arrangement drawing; when, however, the system is complicated a special perspective drawing is prepared. The object of these drawings is to give a general idea of the run of pipes, method of support, etc., and to provide a means of calling up the various brackets, and connections, etc.

(*c*) A piping diagram quoting length, sizes, diameter and end connections.

In some cases where a confined space has to be used for many important systems, and particularly where accessibility is a first consideration, it has been found most valuable to make a complete mock-up so that the exact position of joints and connections can be determined. This has been used for example on a complete engine installation where pipe lengths and shapes were worked out in this way and finally general accessibility and repair and maintenance requirements checked and demonstrated.

8.3 *Drawing numbering.* As in the matter of drawing presentation this matter has been approached with a view to obtaining the maximum value from some form of designation numbering without forcing a system into use which is difficult to understand and operate. In practice the result has been very simple—a six-figure drawing numbering system is used, the first figure indicating the aircraft type and the next one of the main groups or breakdowns into which the aircraft structure is divided. Within each of these groups, e.g. the outer wing, batches of numbers are allocated covering structure, aileron, controls, electrical system, etc. In this way it is only necessary to remember the significance of ten or less numbers which correspond to the ten or less major assemblies (the sub-group drawings will not be known to the general staff but they will have a significance

to those dealing continually with them, for instance in the drawing and planning offices). This system aligns itself accurately with the conception of a completed unit with all systems installed, which is assembled to the aircraft at a late stage shortly before flight.

8.4 *Legibility of drawings.* Every effort must be made to produce drawings which are, and remain, easily legible. For this no pencils harder than 3H are allowed, and a much softer grade is used for lettering. Drawings are traced as quickly as possible and in any case before they get into a bad condition, which with paper originals occurs very easily with the frequent re-issues and the large number of copies per issue required under present day conditions of widespread dispersal, sub-contracting, etc.

Tracing, formerly a difficulty, has been satisfactorily carried out at an office staffed by part-time women workers; beyond this there has been constantly sought some means of producing more permanent originals and more satisfactory prints from paper drawings without tracing, and a successful trial has now been made of a photo-printing process using celluloid sheet from which a much better contrast from pencil original drawings is obtained in the printing, entirely without tracing. This system and material lends itself admirably to the hard wear and tear and continual alteration to which aircraft drawing originals are subject, and on which so many of the alternative systems which are at first attractive, fall down. It eliminates hand tracing and suffers only from the disadvantage that the reproductions are not to scale; in practice this has not proved such a disadvantage as was anticipated and the use of the system has been considerably extended.

8.5 *Lofting.* In the past there has frequently been difficulty in translating design drawings into production aircraft particularly as regards interpretation and dimensioning of curved surfaces. Many of these difficulties are overcome, with economy in both time and labour, by the adoption of lofting. This comprises the laying out, preferably at full scale, of the shape of particular parts on metal in such a manner that they can then be reproduced accurately either for prototype manufacture or for the making of jigs and tools. Much thought has been given to the method of reproduction and schemes in use fall into one of two categories:—

(*a*) Contact.
(*b*) Photographic.

In general, contact processes, for example the Westland and Robinson, are the cheapest and simplest to operate and meet a large proportion of day to day requirements, but they can suitably be assisted with photographic reproduction for particular applications where a special advantage may be the ability to alter scale.

Lofting should be viewed as an engineering function and the data given by it as a definite part of the manufacturing information. Preferably the loft department will be responsible for the actual drawing of the loft lines, for their reproduction, and for the cutting up and preparation of the master templates which will then be issued to the production departments. This places an extra load on the engineering department in spite of enabling a reduction to be made in the number of paper drawings. On the other hand this is more than compensated for by the saving in the amount of work necessary in the tool room in developing from dimensioned drawings, and later in the production departments in getting properly co-ordinated tools. Over all there should, by the adoption of lofting, be a saving of several months in the total development time of a new aircraft.

In manning a loft room much of the labour can suitably be obtained from those skilled in pattern work.

The number of templates issued by a loft department will be fairly large and on, for example, a medium-sized aircraft, say, 850 to 1,000, this, of course, being associated with some reduction, although not a proportionate one, in the number of drawings required.

As with other innovations, lofting has been applied just so far as a real need for it has become apparent, and used in this way it has rendered invaluable service. Application has in particular been to curved contour members of wings, fuselages, nacelles, tail units, etc., which have in the past been most difficult to dimension accurately on drawings. The substitution of the physical and almost completely reliable standard of reference which is available to all departments, has in large measure eliminated the opportunity for error, misunderstandings and alterations at a late date which began to become too frequent with the modern metal aircraft prior to lofting.

Where lofting is used it is the writers' invariable practice not to dimension or define the contour except by reference on the drawing to a mould loft template number.

The lofting system provided comprises the marking out, full size, on dyed light alloy sheets, of the basic shapes. From these basic lines the contours actually required are marked off on steel printing sheets on which the final line is deeply scribed. The printing sheets are then covered with printers' ink, and, suitably backed up by a rubber cushion, it is found that the impression can be reproduced on any number of a large range of materials such as steel, light alloy, wood, fibre board, etc. The " prints " are taken off for both drawing office and inspection record and one or more steel templates are printed at the same time for works or tooling use. The steel templates are printed individually and filed to contour, but the inspection and design templates are frequently retained as a family, as in general they do not require to be cut out to contour.

The Westland lithographic reproduction practice, which has proved very successful in practice, was described in detail in an article in " Aircraft Production," January, 1942. Illustrations of some of the processes are given in Fig. 6, with the lay-out used in Fig. 7.

A great advantage of the mould loft which is not always appreciated is that alterations of shape to accommodate new or modified equipment can often be made in a pleasing manner while yet retaining the maximum of the original and basic form. It has frequently happened in the past that a change is commenced with this intention, and due to the small scale drawing on which the work was carried out, it is only found out too late that either some " unfairness " of line must be accepted or else the alteration must be made more far reaching than would have been necessary had the shape been properly co-ordinated in the first place.

8.6 *Modification procedure.* Much can be done to assist in the co-ordination of design and production in the presentation of modifications. A system has been evolved at Westland, and proved over a series of years to be successful, in which modifications are issued in preliminary form in advance of the full M.A.P. procedure. This preliminary form starts from the following supposition:—

(*a*) That although a trial installation will be made, incorporation into the production line will necessarily lead to further minor changes, and that drawings should therefore be kept in a fluid state until the modification is properly in production.

(*b*) That the manufacturing departments are much more immediately concerned with adequate design information supplemented by lists of parts new, modified or scrapped, than they are in receiving full and final production drawings and schedules.

Accordingly the preliminary modification information at Westland consists of a preliminary modification sheet listing parts and drawings affected, supplemented by drawings, all of which carry new numbers. These may either be new detail drawings, or where they are assemblies they are prepared either as simple extracts from existing general arrangement drawings or by taking a copy transparency of the existing drawing, giving it a new number, and altering it to show and call

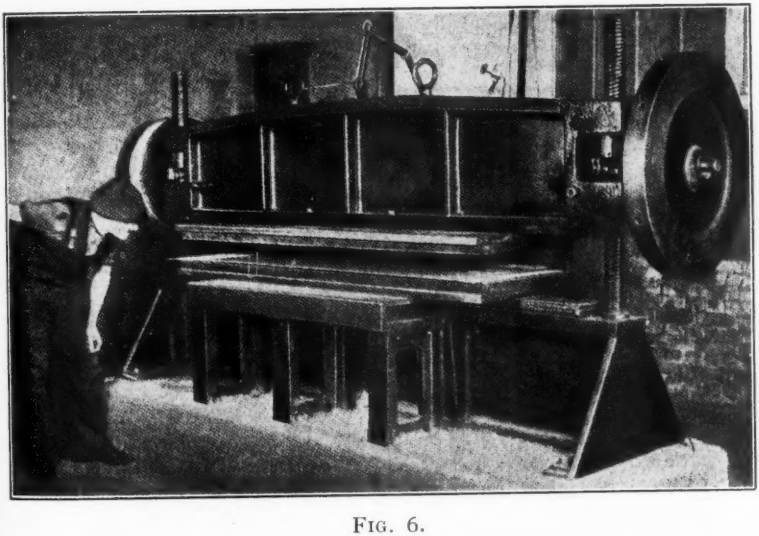
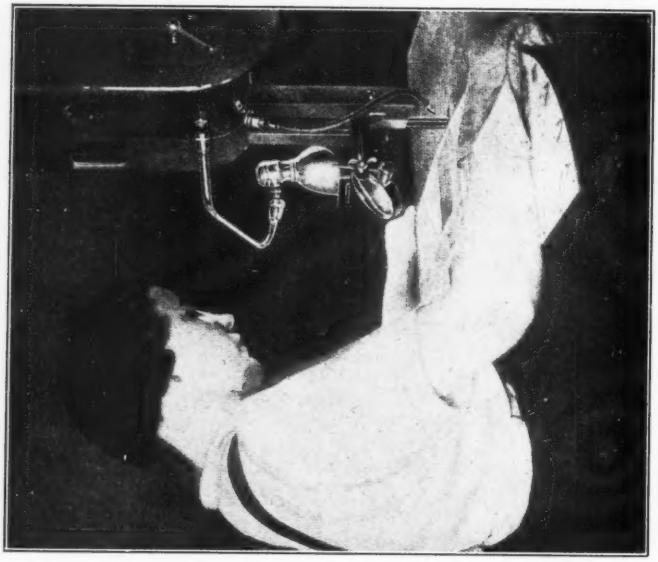


FIG. 6.



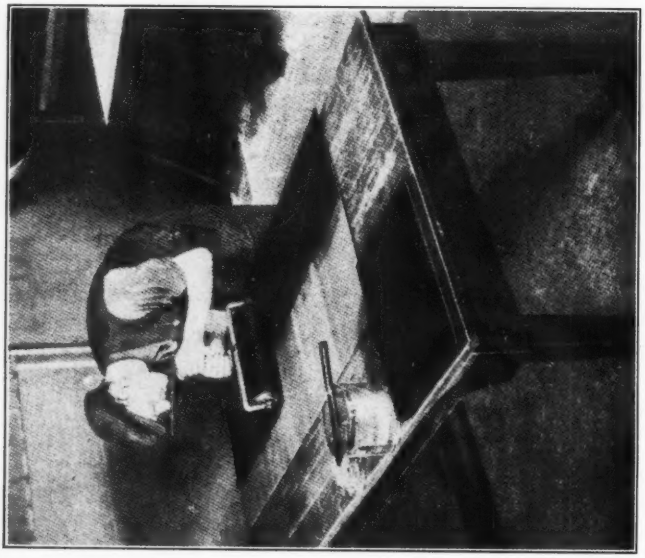
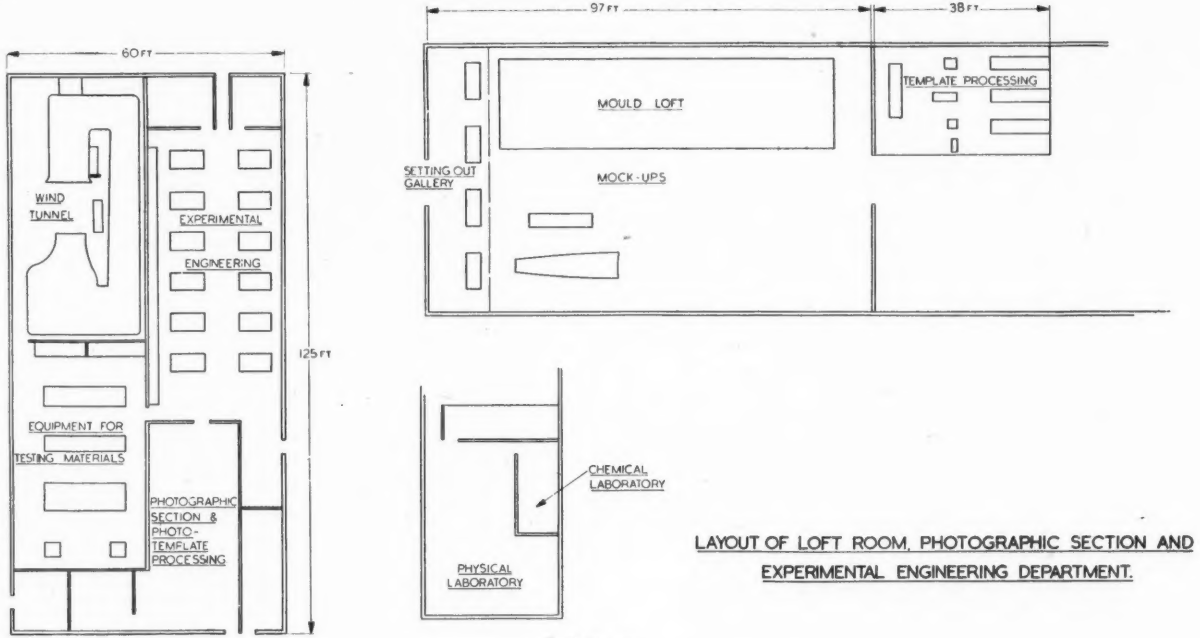


FIG. 6.



LAYOUT OF LOFT ROOM, PHOTOGRAPHIC SECTION AND EXPERIMENTAL ENGINEERING DEPARTMENT.

FIG. 7.

up the modification, everything else being left unchanged. An example of this procedure is shown in Fig. 8. It should be noted that the " extract " drawings bear the number of the master drawing together with the modification number.

PRELIMINARY MODIFICATION SHEET.

To: R.T.O.
Mr. Fearn.
Mr. Tucker (4 copies).
C.I.
Insp. Dept.
W.A.
Planning Dept. (2 copies).
Jig and tool.
Prod. Manager (12 copies).
Estimating Dept.
A.I.D. (2 copies).
Mr. Matthews.
Mr. Dodge.
Mr. Lea.

Note: Authority to incorporate this modification is embodied in the Order Sheet issued by the Sales Dept., and no work is to be put in hand until same is received.

29th December, 194
T/CJT/RDF/3,239.

WESTLAND " WHIRLWIND."

Modification No.: Whirlwind/148.
Class No.: 34.
Title: Strengthened Suppressor Mounting Bracket.
Reason and General Description: Failures due to vibration have occurred to the Suppressor Mounting Bracket, and this modification introduces an additional attachment bracket from the Suppressor Mounting to the Engine Mounting.
Types Affected: Whirlwind.
Trial Installation: Not required.
Incorporated in A/C No.:
Unit Affected:
New Drgs.: 81801 C Bracket for Suppressor Mounting.
Modified Drgs.: 76822 Engine Bearer.
†80951 Assy. of Booster Coil Suppressor Mounting.
†80952 Bracket for Port Booster Coil.
Cancelled Drgs.: Nil.
New Parts Required.

Part No.	Description.	No. off per a/c.
81801	Bracket	1
AS.157/403	Rivets, $\frac{1}{4}$ in. dia. Snap Head	3
A.1-2C	Bolts, 2.B.A.	1
C.P.1.	Nut, Simmonds, 2.B.A.	1

Redundant Parts: Nil.

New drawings and extracts of drawings marked † are issued with this Preliminary Modification Sheet.

Technically agreed for D.T.D. Date:
Technically agreed for D.A.L. Date:

FIG. 8.

In this way the real information required is got out very quickly while the master drawings are not altered until the modification has been tried out and approved. This is a great advantage in the event of a big modification which may take some time to test, as the master drawings which will ultimately be affected can carry on in production and be subject to normal drawing office proce-

dure in the interim. Not infrequently also modifications are cancelled while still in the trial installation stage—the extract system with its avoidance of general alterations until a late stage is then at considerable advantage.

The arrangement has such practical advantages that it has recently been the subject of discussion between the Ministry of Aircraft Production and the Society of British Aircraft Constructors, and it has been agreed that the M.A.P. modification procedure is shortly to be modified to incorporate some of the advantages of the Westland system.

8.7 *Material supply.* In practice the supply of raw materials can very materially affect the development period; they must be ordered, even at some commercial risk, very early and before the precise quantities can be ascertained. The following are important factors on material supply.

8.7.1 *Ordering.* At the earliest possible moment in the design of the prototype, the authors' firm make out a special material list in the development design office covering both special raw materials and bought-out or embodiment loan items. An advance copy of this list forms the basis of requisitions for prototype material, usually long before the designs which will use the material are completed. Other special materials such as castings must, of course, be complete as to design before they can be ordered, and in this case every effort is made to complete such designs in advance of all others and in any case at least six months before the prototype is due to fly. When, in addition to prototypes, an order off the drawing board is placed, a number of production sets of these special materials are requisitioned at the same time; in addition a rough bulk material list covering standard materials is compiled by the design office and used as the basis of advance production ordering. Such a list is necessarily only 80 per cent. complete but it is of very real assistance in the initial production stages.

As individual designs are subsequently released for production they are reviewed in the works planning office, who compile complete manufacturing material schedules, and it is at this stage that complete material lists become available. It is then possible to allocate materials already ordered on the advance list against the designs as issued, or if the design calls for more material than has been ordered or for small quantities of material which were not included in the advance list, it is still in general possible to place orders in time for production. A simple system is employed for automatically building up these bulk material ordering lists from individual detail master process sheets which specify the manufacturing operations, tooling and material requirements, and also are later intended to form the basis of forecast estimates.

8.7.2 *Material standardisation.* The period of development will be reduced if as far as possible standard materials are employed. There can be a very drastic limitation of the types and sizes of material employed, and this will reduce draughting time and, even more important, will reduce the period taken to obtain raw material; in war time this is one of the largest and least controllable elements in the development period. The smaller the number of material types employed the easier it will be for the material suppliers to produce by substantial production batches reasonable quantities of material. The need for such standardisation became apparent at Westland in compiling the production material lists for the Lysander from prototype drawings, where it was found that there were many cases where only a few inches of bar and tube of a certain type were employed; accordingly at the expense of some re-design a new material list was drawn up for production, and by it the variety of materials was reduced to less than one-half those used on the prototype. This practice has been continued, and although it is found necessary to introduce a few special materials for a particular aeroplane type, these are only included in the standard list if it appears that they will have to be used

beyond the life of that particular type. This practice makes it more easy, in the earlier stages of development, to draw some material requirements from the firm's own basic stocks. Fig. 9 indicates the variation which can occur in the number of types, specifications and sizes of materials employed in different aircraft, and shows how far this process of simplification may be taken.

COMPARISON OF MATERIALS EMPLOYED IN VARIOUS AIRCRAFT IN TERMS OF SPECIFICATIONS AND DIMENSIONS.

Aircraft	1 Lysander	2 Whirlwind	3 Spitfire	4 Barracuda	5 Welkin
Class of material—					
Steel sheet	18	11	36	26	18
Strip		2	2	52	5
Bar	80	80	136	237	80
Tube	64	37	54	167	33
Forgings	20	25	74	133	4
Light alloy sheet	25	37	38	34	45
Strip	28	21	12	11	12
Bar	77	72	67	152	84
Tube	77	66	55	99	56
Forgings	38	68	79	266	10
Castings	56	63	118	162	142
Extrusions	39	58	12	47	25
Other non-ferrous metals ...	53	18	20	120	21
Total	575	558	703	1506	534

FIG. 9.

8.7.3 *Programming.* In programming material supplies for a new development it is essential that there be a reservoir of materials such that economical manufacturing batches can be put through the production shops at an early stage. There should also be sufficient material, particularly bar, available to cope with shortages which are so often experienced on parts normally purchased fully fabricated, but which have temporarily to be made in the manufacturer's own works; these include, for example, bolts and nuts.

8.7.4 *Development time for wrought material.* The time taken to develop certain forms of wrought materials, particularly forgings and castings, will generally be very long under war conditions; for large forgings up to 12 months may readily be taken. It is therefore essential that the design planning should be such as to produce the drawings for these items at as early a stage as possible and in advance of other parts, such as stressings or fabricated structures, for which a shorter development period suffices. The time taken in obtaining satisfactory forgings and castings will be found to have had a profound influence on the over-all development period of many projects.

Assistance can be given on this problem by forging suppliers having very adequate tool room resources and by their being able to supply a few sets of carefully made hand forgings while still requiring machining; this will result in a substantial saving as compared to working from solid stock.

8.8 *Standardisation.* Every effort must be made to reach a common standard and create a method of doing a certain job in a certain way, i.e. one which is considered by the design firm to be a good design and acceptable production practice. Such choice of methods is necessarily somewhat arbitrary, but it is

essential, particularly where staff have been built up from many and diverse sources. An important section of this has already been dealt with under material standardisation, but the subject also includes the adoption of general standards of design, in particular those on which the Technical Sub-Committee of the Society of British Aircraft Constructors has done such good work, and those established by jig and tool designers and referred to below.

Naturally it is important that the various designers and draughtsmen should be fully aware of the standard methods and materials of the firm, and accordingly every draughtsman is issued with a handbook which, in addition to describing the standard rules and practices, contains a large number of data sheets dealing with such matters as designations of standard aircraft bolts and nuts, rivets, etc., standard extrusions, blanking tools; everything in fact which is likely to be commonly used is collected from the various aircraft design memoranda, material and standard specifications, Air Ministry publications, makers' catalogues, etc., and summarised in this booklet. Sample pages for this manual are given in Figs. 10 to 13.

STANDARD DESIGNING MATERIALS.

TUBE:—GAUGES AVAILABLE.

	NON-FERROUS.				FERROUS. Mild Steel.		
Outside Dia.	Alum. D.T.D. 310.	Alum. T.9.	Dural. T.4.	Copper T.7.	T.35.	T.45.	Steel for Piping D.T.D.
$\frac{3}{16}$ in.	22	—	—	20	—	—	24
$\frac{1}{4}$ in.	22		(17 (22	20	22		24
$\frac{5}{16}$ in.	20		17		22		22
$\frac{3}{8}$ in.	20		(17 (20		22		22 $\frac{7}{16}$ in. × 20
	$\frac{7}{16}$ in. × 20		(22				
$\frac{1}{2}$ in.	20		(17 (20			(17 (20 (22	20
$\frac{5}{8}$ in.	20		(17 (20			20	
$\frac{3}{4}$ in.	20		(17 (20			(17 (20	
$\frac{7}{8}$ in.			(17 (20				
1 in.	20		(17 (20	20		(17	
$1\frac{1}{8}$ in.	20		(17				
$1\frac{1}{4}$ in.	20		17	20		(17 (20	
$1\frac{3}{8}$ in.		17	17 (20				
						(17 (20	
$1\frac{1}{2}$ in.		17	17				
$1\frac{5}{8}$ in.		20	17				
$1\frac{3}{4}$ in.			17				
2 in.		17	17				
$2\frac{1}{4}$ in.		17	17				
$3\frac{1}{4}$ in.							

FIG. 10.

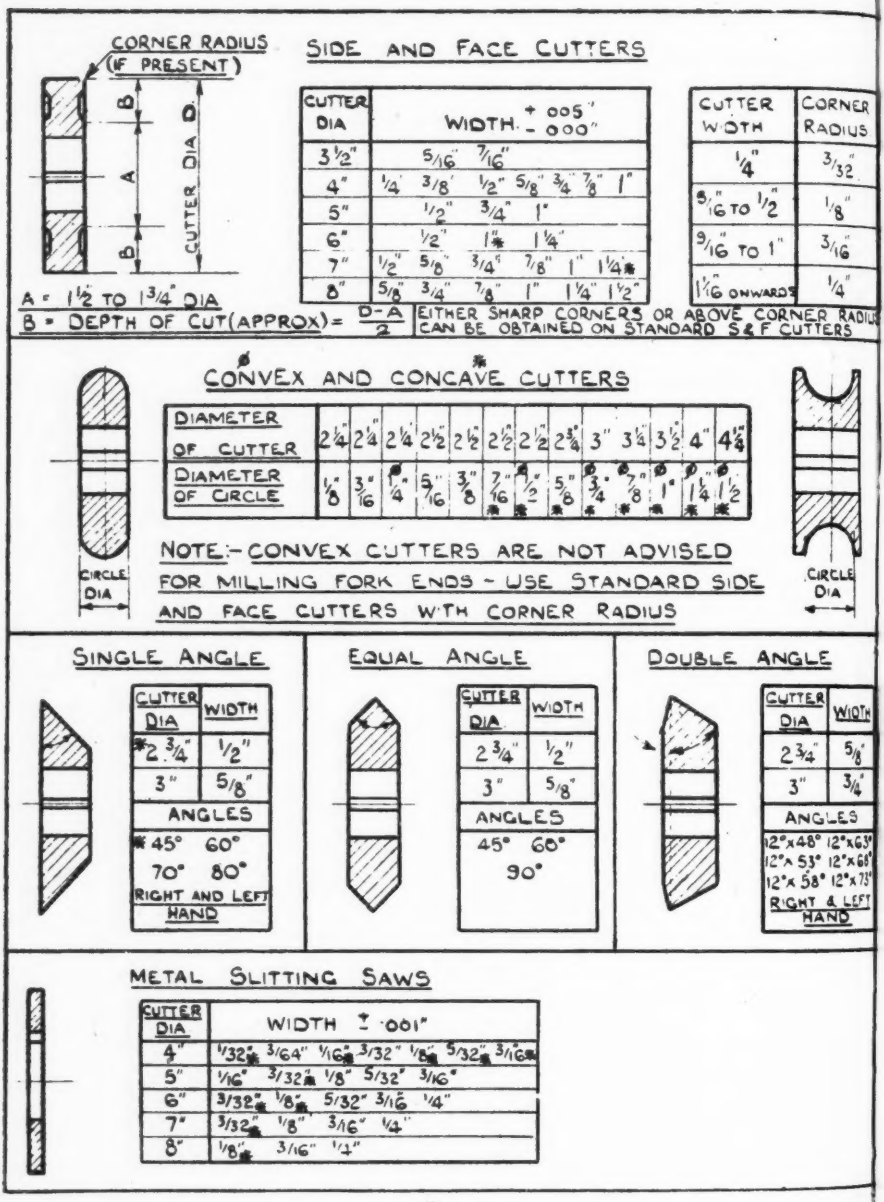


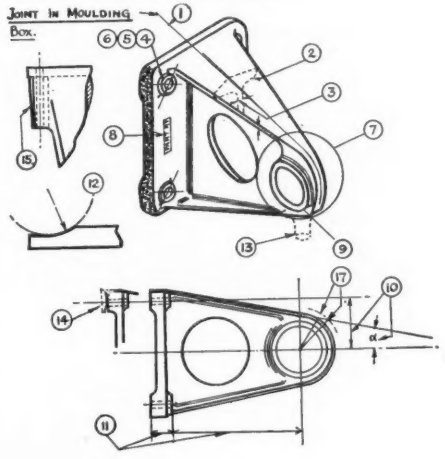
FIG. 11.

Milling cutters.

* or ϕ denotes available from tool stores. Machined parts requiring use of any of above not marked * or ϕ may however be employed as all cutters above are standard sizes. See also Westland Tool Standards Handbook for lists of other cutters available on tool stores.

DESCRIPTION

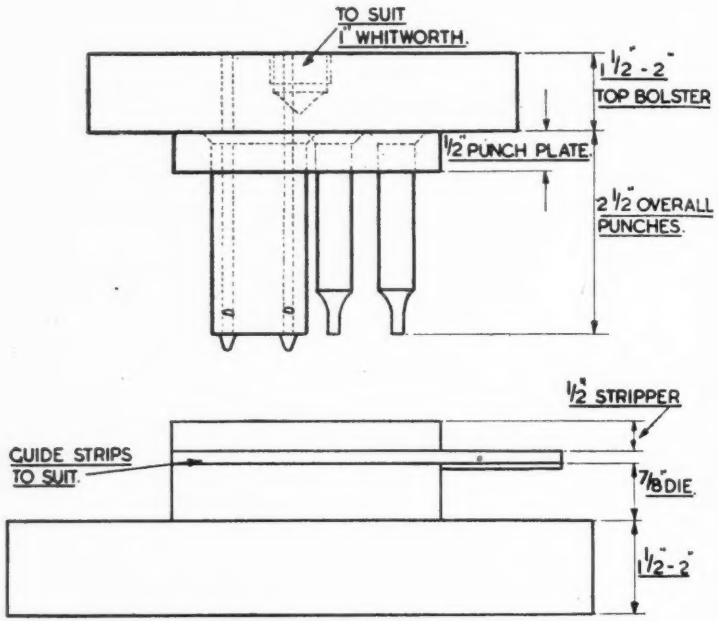
DETAIL DESIGN OF CASTINGS.



1. Consider probable method of casting.
2. Allow for " draw " of pattern where possible.
3. Show min. thickness where unstressed.
4. Provide bosses for gang-milling instead of spot facing or special machining.
5. Bosses up to and including 1in. diameter to have an extra $\frac{1}{8}$in. metal on the nominal dia. to allow for eccentric holes.
6. Call for clearance holes if allowable.
7. Ring highly stressed areas.
8. Show place for part No. and inspection stamp.
9. Show "f" where machining is required.
10. Positioning of centres or other points should be by dimensions and not angles.
11. Important dimensions to be directly given and not as shown.
12. Arrange for simplest possible machining operations using standard cutters.
13. Ascertain if any jigging pads are required.
14. Try to avoid a separate casting for R. and L. hand, *e.g.*, the R. and L. hand angled bosses would be made from one large boss.
15. Avoid the use of long pockets.
16. Avoid the necessity for coreboxes in the casting operation.
    The drawing should contain the following information in every case.
    Material specification and alternatives.
    Protective treatment.
    Class No. of casting and class letter if Class I.
    No. off.
17. Show minimum and maximum radii allowed to facilitate machining and inspection.

FIG. 12.

STANDARD PRESS TOOLS. 'A' TYPE. (PLAIN).



NOTE:- PUNCHES TO BE D.F. IN PUNCH PLATE, S.F. IN STRIPPER & NECESSARY CLEARANCE ALL ROUND IN DIE.

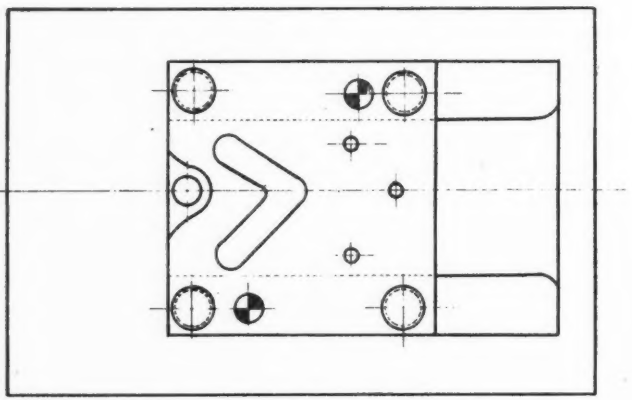


FIG. 13A.

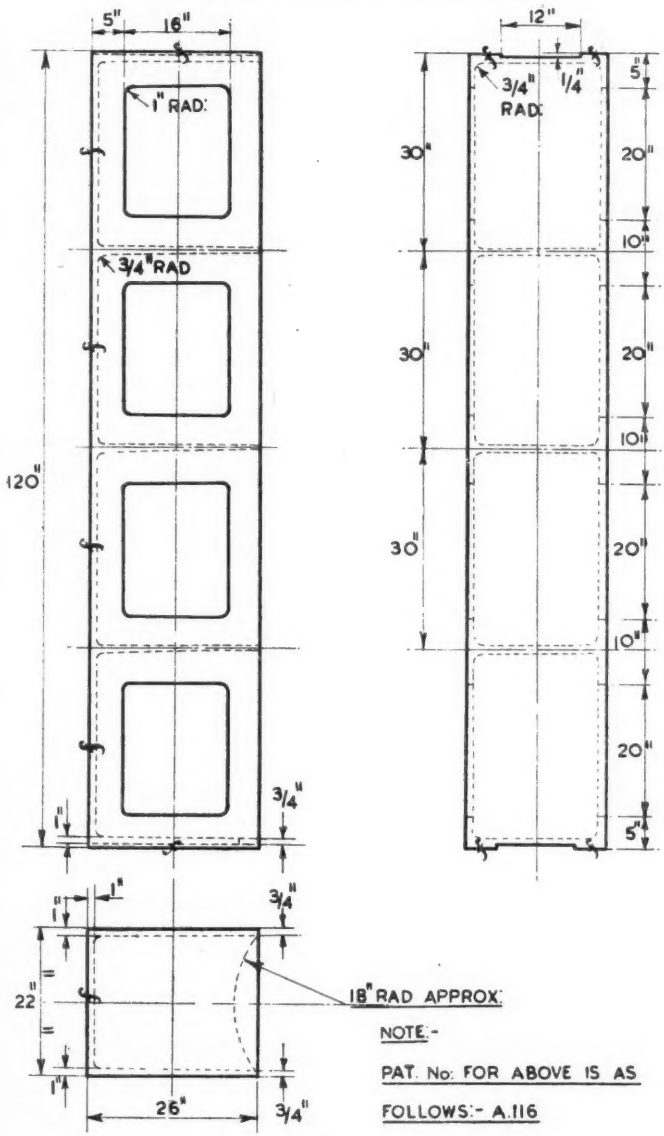

STANDARD BASE CASTING
5"
16"
1" RAD.
3/4" RAD
120"
3/4"
1"
1"
3/4"
22"
1"
26"
3/4"
18" RAD APPROX.
NOTE:-
PAT. No. FOR ABOVE IS AS
FOLLOWS:- A.116
12"
3/4" RAD.
1/4"
5"
30"
20"
10"
30"
20"
10"
30"
20"
10"
20"
5"

FIG. 13B.

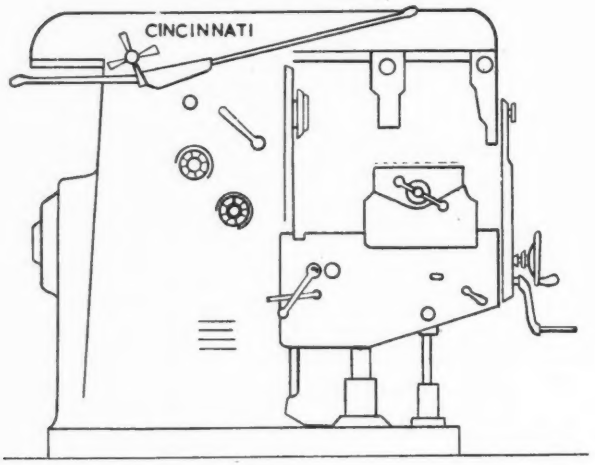


FIG. 14.

Standard machine tool capacity chart.

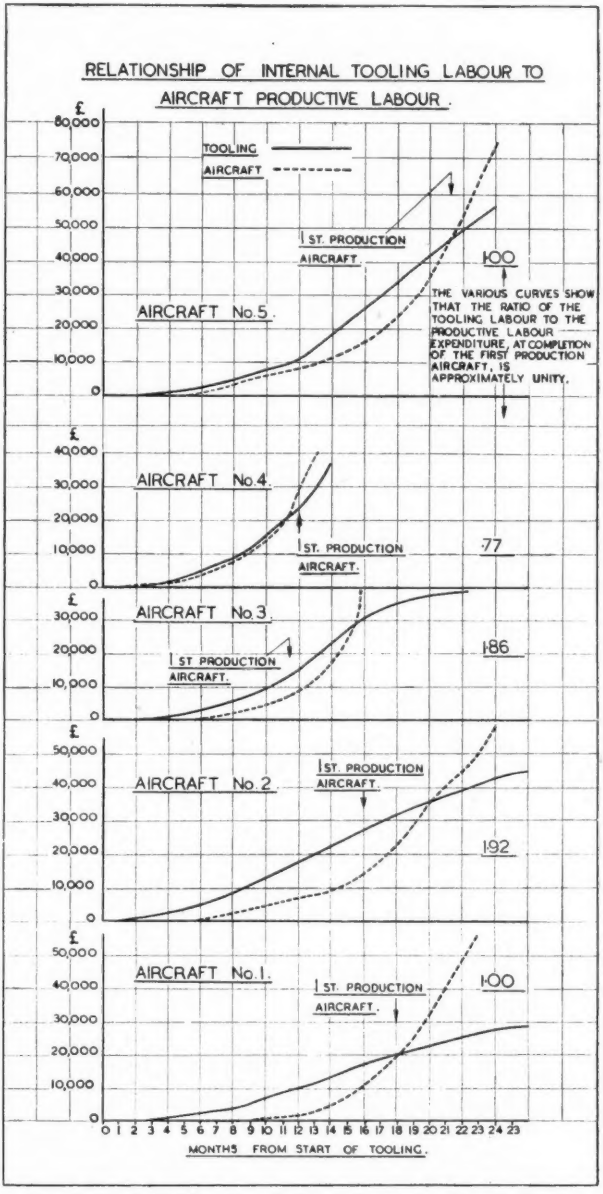
Description of machine	Cincinnati No. 2. Horiz milling machine.	
Working surface of table...	49 × 12	Feeds inches minute $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$, 1, $1\frac{5}{8}$,
T slots	3 off $\frac{11}{16}$	$1\frac{3}{4}$, $2\frac{1}{8}$, $2\frac{3}{4}$, $3\frac{5}{8}$, $4\frac{5}{8}$, $5\frac{3}{4}$, $7\frac{5}{8}$.
Centres of T slots ...	$2\frac{5}{16}$	$9\frac{7}{8}$, $12\frac{3}{8}$, $15\frac{3}{8}$, 20.
Traverse vertical	19″	Speeds r.p.m. 20, 26, 32, 40, 47, 60, 74, 92, 116, 141, 179, 222, 262, 331,
Traverse longitudinal ...	28″	414.
Traverse cross	10″	500.
Maximum spindle to table top	$19\frac{3}{16}$	—
Arbors	1″ dia. × $1\frac{1}{4}$ dia.	—
Motor required h.p. 1,750 r.p.m.	—	—
Floor space	98″ × 98″	—

8.9 *Tooling.* The following are important aspects affecting the tooling of an airframe:—

8.9.1 *Standardisation.* It is essential that the jig and tool design office should maintain close liaison with the aircraft designer's office to see that suitable standards are incorporated in the drawing office manual, as mentioned above, for the basic elements of tooling, in particular to cover such matters as milling cutters sizes, blanking and piercing die shapes and sizes, hole diameters, etc. Typical standard sheets are given in Figs. 13-14.

In addition they can effect a large amount of detail standardisation within their own office; this can include the use of standard die sets, clamping devices, pins, set screws, etc., small fixtures, standard bases (made, for example, from mild steel section machined in multiple lengths) for machining fixtures, etc. For assembly jigs it is possible to utilise to a considerable degree a number of basic standard structures in either cast iron tubular or welded mild steel.

8.9.2 *Influence of type of equipment.* The type of tooling equipment available will have some influence on design although frequently the particular manufacturing process will have been called into existence by the necessities



Aircraft No. 5—Welkin; Aircraft No. 4—Barracuda; Aircraft No. 3—Spitfire; Aircraft No. 2—Whirlwind; Aircraft No. 1—Lysander.

FIG. 15.

or exigencies of design. The employment of drop hammers, now giving way to some degree to the stretching machine or simple wooden or cast draw dies, and the use of the rubber bolster press have a considerable effect on the development period.

8.9.3 *Rate of initial tooling.* Assuming that the construction of the prototype is not simply a flying model but is to represent the actual operational design, then some amount of tooling can be carried out and applied with resultant economy of labour to the construction of the prototype itself. This will be effected by the actual processing of prototype drawings, preferably in a special section of the planning office temporarily allocated to this work. The design and manufacture on a priority basis will then be carried out of key jigs or tools carefully chosen as being unlikely to be affected by any design changes. This procedure is particularly valuable in obtaining at an early stage detailed production criticism of the design so that issue of production drawings from the design office can follow with confidence the issue of prototype drawings much earlier than would otherwise be possible.

Fig. 15 shows to a time basis for the initial production stages of a number of aircraft the rate of expenditure in the constructors' own shops on tooling labour as compared with the direct labour on manufacturing. It will be observed that at the time of delivery of the first aircraft these two labour elements are generally of the same magnitude; in considering this it should be borne in mind that tooling carried out by sub-contract was somewhat greater than that carried out by the firm itself, but the latter is a fair indication of the rate of progress of the whole.

8.9.4 *Economics.* It is most important that the economics of tooling should be thoroughly considered with particular reference to their effect on the time of development. Relatively simple tools, such as, for example, stack drilling and routering templates, will cost less in tool making labour than combination blanking and piercing dies; it may well be found that the cost of the latter in money is only recovered when of the order 500 aircraft are made; very frequently before this number, particularly in the initial stages of development, have been made the tool will have had to be altered. It will also be found that from the viewpoint of economy in labour, while the more complex tool will over a relatively large number of parts produced save in man-hours taking into account both the product and the tool making, the labour saved will be of the unskilled or semi-skilled type, which is in freer supply, while that taken in tool making will be of the most highly skilled type in the greatest demand; if only for this reason the more complicated tool will take the longest to produce.

As an aim, up to about 5 per cent. of the reasonably to be expected value of the aircraft to be produced should, in wartime, be expended on initial or basic tooling. It is desirable at an early stage to allocate the amount estimated to be expended as amongst the main components of the aeroplane and the main types of tools so that there may be control of the expenditure. An example of such a budget is shown in Fig. 16.

8.9.5 *Tool try-out.* As production tooling proceeds it is most important that there be some very clear method of trying out tools, and many of the troubles which have occurred can be traced to difficulties in this procedure. It is a common experience that a large proportion of detail tools obtained normally by the industry, necessarily in wartime by sub-contract, require some sort of alteration or rectification which incidentally absorbs a large proportion of the main constructor's tool making effort. Some of this can be overcome by inspecting the tools and, to the degree possible, trying them out at the tool makers' works, but in any case each tool must be checked finally by the adherence to drawing of the part which it produces and by the

TYPICAL TOOLING ALLOCATION COMPRISING BOUGHT OUT AND INTERNAL TOOLING (£).

Component Tool Type.	Main Planes.	Fuselage and Engine Mounting.	Ailerons.	Flaps.	Tail Plane.	Rudder.	Elevators.	Oil and Other Systems.	Cowlings and Fairings.	Armament and Brake Gear.	Pilot's Coupe.	Flight Controls and General.	Total.
Assembly	40,000	7,500	1,000	500	2,500	1,200	2,000	150	600	1,800	600	450	58,300
Sub-assembly	1,000	400	50	50	500	60	100	—	—	40	250	100	2,550
Machining fixtures ...	7,000	5,500	600	1,100	550	80	150	2,600	1,050	5,250	350	15,000	39,230
Press tools	9,000	8,000	750	500	800	600	1,000	1,750	250	800	100	3,950	27,500
Hand tools	55,000	12,850	3,950	2,650	3,600	1,900	3,250	3,850	1,550	8,400	1,000	22,000	120,000
Total	112,000	34,250	6,350	4,800	7,950	3,835	6,500	8,350	3,450	16,290	2,300	41,500	247,580
												Equipment for final erection	4,000
												Grand total	£251,580

Note:—The ratio of bought out tooling to internal tooling is approximately as 3:2.

FIG. 16.

assembly together of associated details. It has then been found wise and convenient to establish a department in which parts made as to a first small batch from the detail tools are sent for proof assembly into sub-assembly fixtures. There will always be difficulty at this stage, reduced to the degree that it has been possible to undertake the detail tooling of particular sub-assemblies as units. There should be definite and close connections between this pre-production assembly proving department and the design office, jig and tool office, inspection and production shops such that by routine any necessary changes to guarantee satisfactory assembly are incorporated in the different parts and the consequential changes definitely made on drawings and tools, the whole finally being re-checked by passing again through the

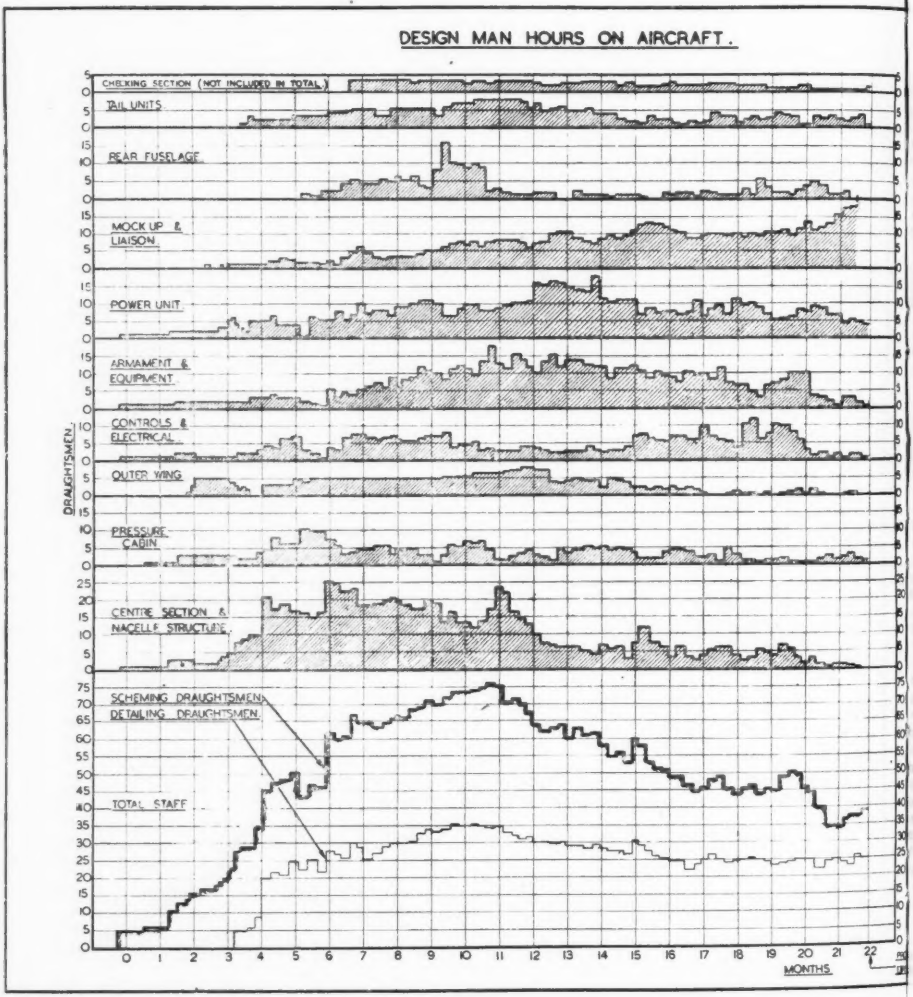


FIG. 17A.

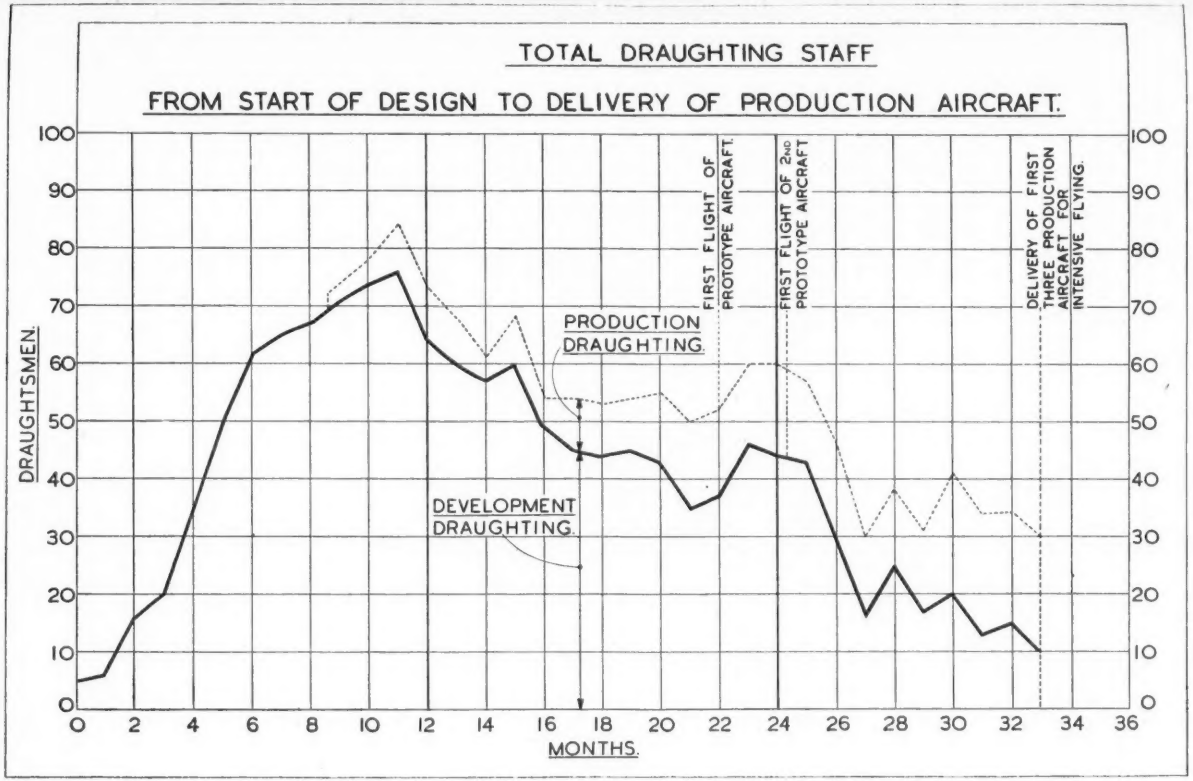
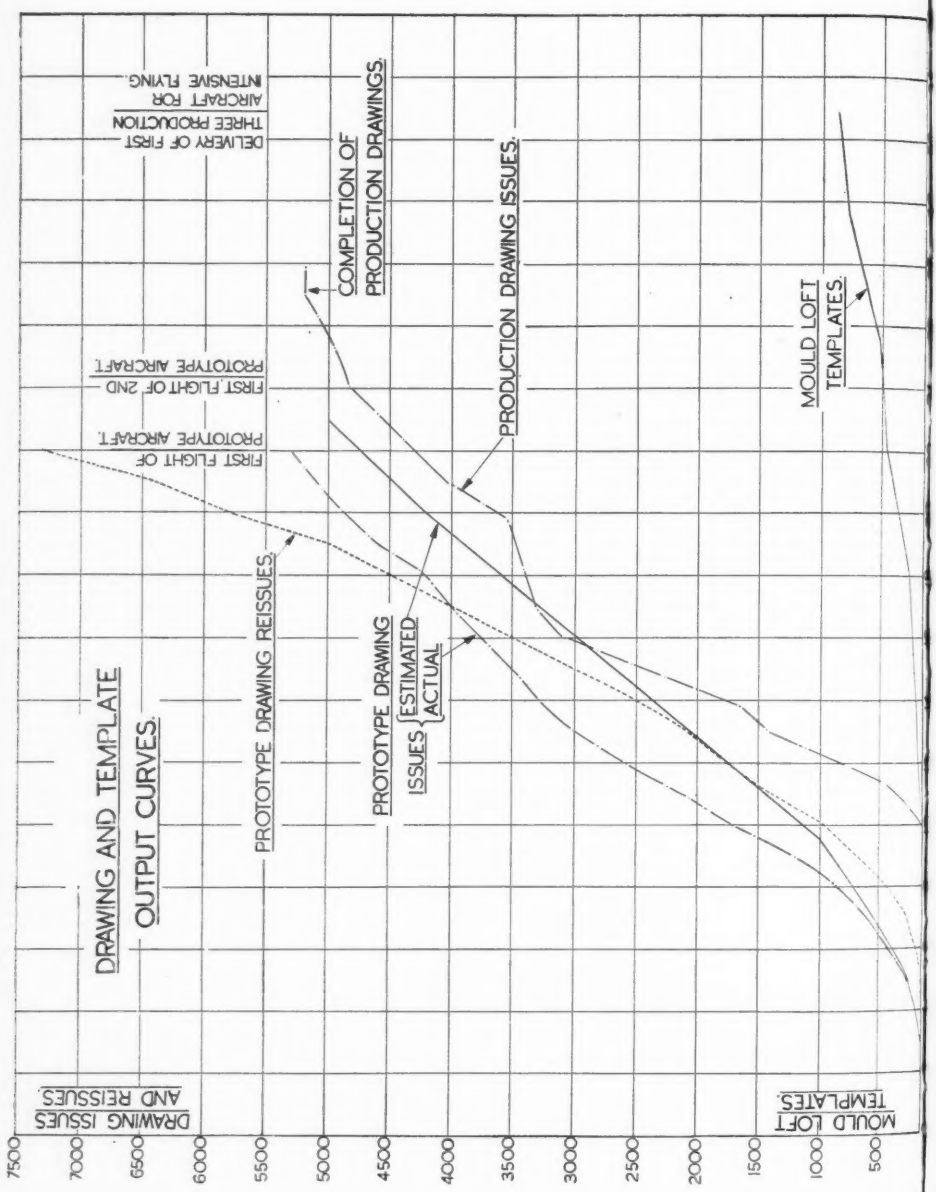

TOTAL DRAUGHTING STAFF
FROM START OF DESIGN TO DELIVERY OF PRODUCTION AIRCRAFT.
DRAUGHTSMEN.
MONTHS.
PRODUCTION DRAUGHTING.
DEVELOPMENT DRAUGHTING.
FIRST FLIGHT OF PROTOTYPE AIRCRAFT.
FIRST FLIGHT OF 2ND PROTOTYPE AIRCRAFT
DELIVERY OF FIRST THREE PRODUCTION AIRCRAFT FOR INTENSIVE FLYING.
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
0 10 20 30 40 50 60 70 80 90 100

FIG. 17B.


DRAWING AND TEMPLATE
OUTPUT CURVES
DRAWING ISSUES AND REISSUES
MOULD LOFT TEMPLATES
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
PROTOTYPE DRAWING REISSUES
PROTOTYPE DRAWING ISSUES {ESTIMATED ACTUAL
FIRST FLIGHT OF PROTOTYPE AIRCRAFT
FIRST FLIGHT OF 2ND PROTOTYPE AIRCRAFT
COMPLETION OF PRODUCTION DRAWINGS
PRODUCTION DRAWING ISSUES
MOULD LOFT TEMPLATES
DELIVERY OF FIRST THREE PRODUCTION AIRCRAFT FOR INTENSIVE FLYING

procedure. It will be clear that under the day to day stresses of aircraft construction discretion has to be exercised, and that the adoption of such a scheme does not eliminate production development difficulties.

8.10 *Budgeting.* In order to secure adherence to a programme of development and production it is essential that there should be adequate budgeting and through it control. Probably this will take the form of:—

(*a*) An estimate of design man-hours on the aircraft as a whole, subdivided into convenient sections with a forecast of the rate at which they must be expended. It should be possible to check actual performance against the forecast week by week, not more than a week in arrear, and no very elaborate paper system is necessary for this. An example of this is given in Fig. 17.

(*b*) Forecast of the number of actual drawings and mould loft templates involved and the rate at which they are expected to be completed, this again to be compared weekly with actual performance. An example is given in Fig. 18.

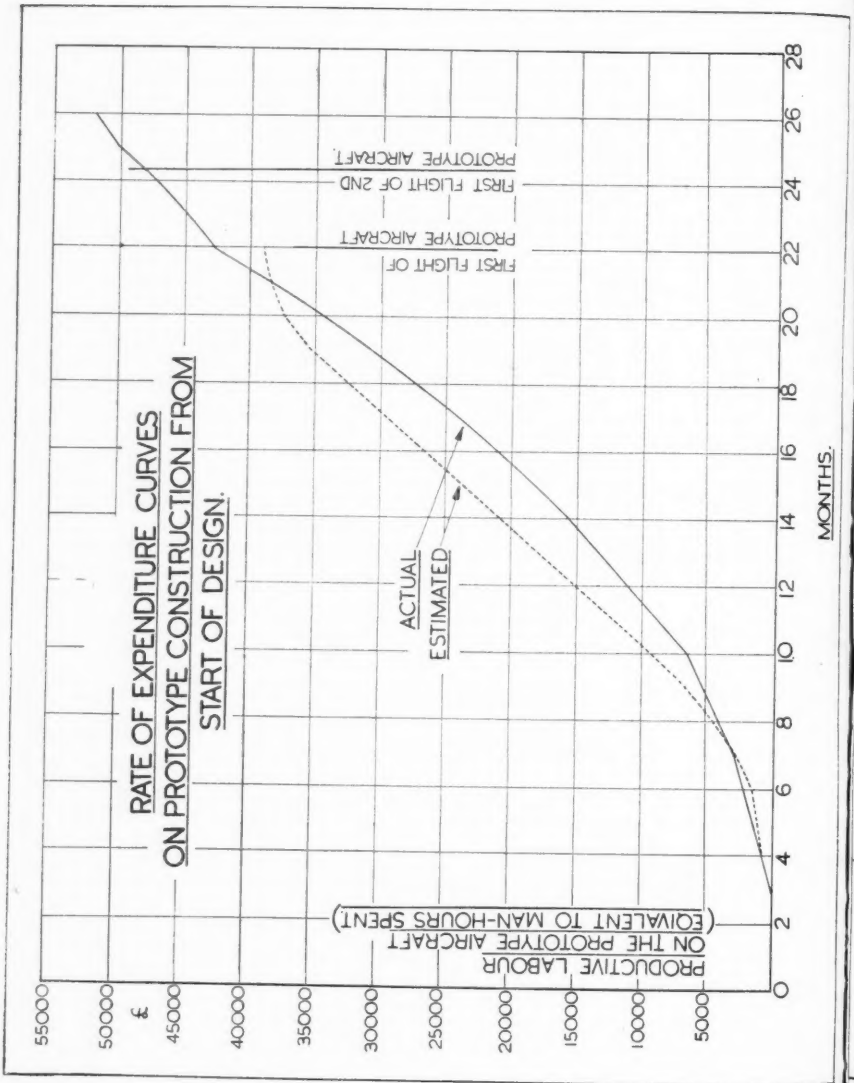
(*c*) For prototype construction a forecast of the number of productive man-hours estimated to be required to first flight and, based on the estimated rate at which the design information will be supplied, the rate at which these can be expected to be effectively expended. This is a difficult forecast to make, but can be made with reasonable accuracy by comparison with previous projects, suitable factors being introduced for variations in size, weight and complexity. It is essential that this budget should then be used as the medium of control in the experimental shop and that each week the man-hours called for should be effectively spent. Frequently it will be found that on the ideal programme this is not possible, but that by bringing forward some other detail or unit not required so early the labour can still be absorbed; it is essential to do this as otherwise any lag that is allowed to creep in will lead to such large peaks of labour demand later as to be virtually impossible to overcome. With a normal wages and cost system it should be possible to have the labour absorption figures for control purposes within two weeks of the labour expenditure being increased. An example is given in Fig. 19.

8.11 *Conditions of working.* There are a number of important factors arising under this heading:—

8.11.1 *Hours of work.* Hours of work have a definite effect throughout the organisation on speed of development, and bearing in mind the long period over which effort has to be sustained on an aircraft project, it is clear that there must be some optimum conditions. War experience indicates that for a design office a working week of 47½ hours, which includes every Sunday normally free and alternate Saturday afternoons, can be continued and that very occasionally spurts for the overcoming of particular difficulties may be obtained within it by additional overtime. A shorter week, especially for senior people, is necessary, however, in peacetime.

Similarly in the experimental and production shops a working week of about 55 hours, including again no normal Sunday working and only alternate Saturday afternoons (although urgent work will, of course, be carried on through these periods by suitable extra overtime or staggering of hours) is economical. Over a period of years in a particular country district where transport is under the control of the works management it has also been found most efficient to start work relatively early in the morning and to concentrate meal breaks so as to finish early in the evening.

8.11.2 *Methods of payment in experimental shop.* A very important matter bearing on prototype construction is the method of payment to be used in


RATE OF EXPENDITURE CURVES
ON PROTOTYPE CONSTRUCTION FROM
START OF DESIGN.
£
55000
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
MONTHS.
PRODUCTIVE LABOUR
ON THE PROTOTYPE AIRCRAFT
(EQUIVALENT TO MAN-HOURS SPENT)
ACTUAL
ESTIMATED
FIRST FLIGHT OF
PROTOTYPE AIRCRAFT
FIRST FLIGHT OF 2ND
PROTOTYPE AIRCRAFT.

MONTHS.

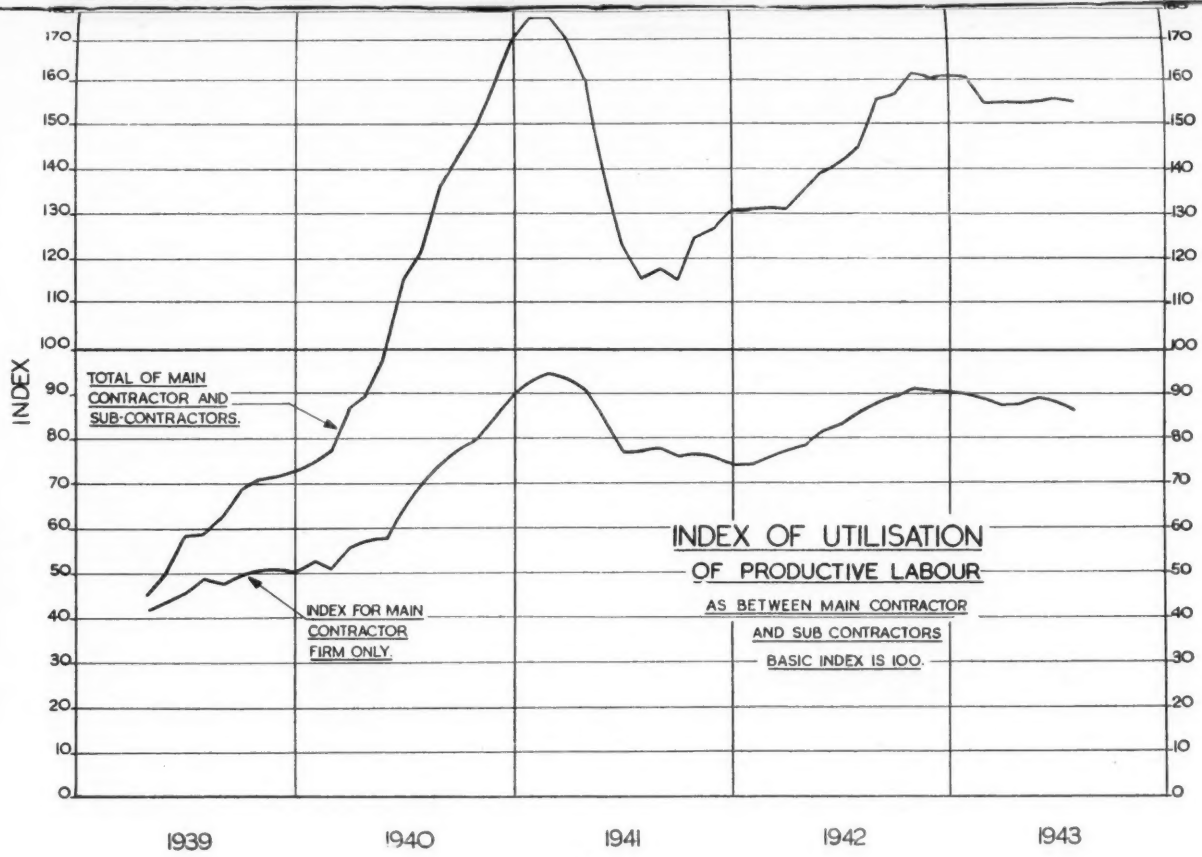
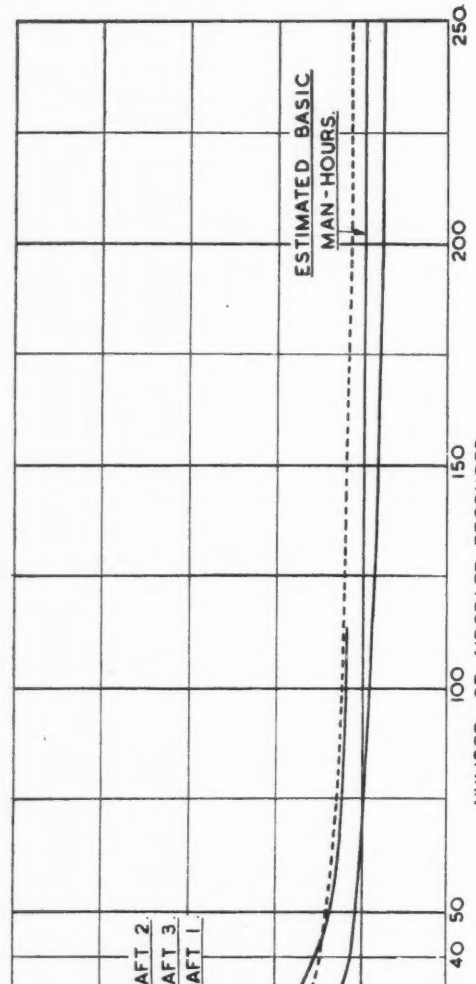


FIG. 20.



Aircraft No. 2—Whirlwind; Aircraft No. 3—Spitfire; Aircraft No. 1—Lysander.

FIG. 21.

Man-hours reduction from initial production stage.
This excludes the effect of major modifications.

the experimental shop. In general it is not possible to pay piece-work although the production departments will generally be operating on this, and probably earning a fairly high bonus. Some of the best labour will be found in the experimental shop and therefore in fairness some form of " in lieu " bonus, ability or merit money has to be paid, and this in practice can be a source of very real difficulty.

8.12 *Extension of firm's own facilities.* It is possible, particularly in wartime, for a firm to extend its own facilities usefully by such arrangements as the following:—

8.12.1 *Sub-contract design.* One or more well-defined components of the aircraft may be allocated to sub-contract design offices. The latter may be either a main design firm with spare designing capacity, or a small detail drawing office supervised by a senior draughtsman from the main office. It is preferable that preliminary scheming of the sub-contracted component be carried out at the parent firm up to the stage where further minor scheming, and detailing only, is required to complete the design.

8.12.2 *Sub-contract production development.* Sub-contractors accustomed to a particular type of component in current production can very frequently undertake with enthusiasm the prototype construction and later production tooling of a new component, thus somewhat easing the load on the parent company's skilled labour and at least helping to compensate for the cases where they have to carry the full burden for the sub-contractors' early production development.

8.12.3 *Prototype construction.* It has been found possible to manufacture certain prototype units either in their entirety or as to a proportion in the production shops. It is frequently found that while it is impossible to take more skilled persons from a particular shop and allocate them definitely to the experimental shop, the foreman can arrange within his own department to form a small experimental section and utilise his own experience and the remaining skill in his shop to produce prototype units; this has been done, for example, on tail units. This also gives a valuable additional check at an early stage on the production qualities of a new design and also speeds its later introduction into production. It is also useful, in manufacturing two prototypes, to have one, the components for which are drawn either from the experimental shop, sub-contractors, or production shops erected in the main erection shop in parallel with that handled in the experimental shop.

8.13 *Continuity of employment.* An interesting study may be made of the manner in which employment is successively transferred on to successive aircraft which pass through the factory. It will indicate the degree of flexibility which is essential in a basic design firm if reasonable continuity of employment is to be maintained. The result may be seen in Fig. 20, which shows the fluctuations over a period of years for a particular factory in the number of persons actually employed referred to the current capacity of the factory expressed as an index of 100; this capacity obviously is conditioned by factors such as the availability of staff and skilled workpeople. The same curve indicates the increase in factory capacity which has been obtained by sub-contracting and the degree to which fluctuations in employment have affected sub-contractors more than the parent company; they are in fact generally able to absorb those due to their working for a number of parent companies from whose different programmes they obtain a useful diversity factor.

8.14 *Man-hours required on early aircraft.* Fig. 21 indicates the variation between the man-hours required to produce early aircraft and those necessary after production has become established, by reference to three examples. This has a definite bearing on the development period as it is clear that apart from the greater number required, the earlier man-hours contain a greater proportion of skilled effort for which labour will be in short supply.

8.15 *Education.* It should be clear from the above observations that a main essential in the securing of good co-ordination of airframe design and production is the availability in adequate numbers of well trained engineers. The aircraft industry is only just beginning to build up a tradition and its future prospects must be sufficiently sound for young men to view it with confidence as a suitable engineering career. Coupled with this the industry must extend its educational facilities and see that a balanced supply of engineers, including highly skilled mathematicians and aerodynamists together with good mechanical draughtsmen and those versed in production engineering problems, are made available to it. It is essential that throughout the educational period men should be in touch with the industry, and to a great degree this can best be secured by apprenticeship, with suitable periods for academic education. There must be very considerable breadth of outlook for the industry as a whole. An example of what is meant here is that at Westland, the best apprentices, having completed their academic and shop training as far as is possible with the local facilities, are being given the opportunity, as a reward for their good work, to go into other industries, with their out-of-pocket expenses paid by the firm for two years, to complete their education to degree standard and to broaden their experience. It is appreciated that many of them may not return to their parent company, but this is immaterial as compared with the vital necessity for building up the standard of the country as a whole.

Recently as an expression of their confidence in the future the company have decided to award each year to the best apprentice a scholarship tenable for three years at the School of Engineering of Cambridge University.

Discussion.

The following is a summary of the discussion which took place on the above paper :—

The President of the Royal Aeronautical Society, Mr. A. Gouge, thanked the authors for presenting a paper of such great interest and importance to the industry at the present moment. Both he and a number of other speakers were of the unanimous opinion that the paper had raised vital issues in the minds of designers and production engineers. He called on Sir Frederick Handley Page to open the discussion.

Sir Frederick Handley Page (Handley Page, Ltd.) thanked the speakers for their very interesting paper, the conclusions of which were backed with some extremely interesting statistics that he had not seen previously. With regard to the subject matter of the paper, he thought that the skilled mechanic did not favour the introduction of perspective drawings, since he took a great pride in the illegibility of the normal three-view drawing to the layman. He referred to the American method of producing perspective drawings by photographing celluloid models and emphasised the fact that such drawings were invaluable to the unskilled labourer, on whom the aircraft industry was now almost completely relying.

Mr. Petter agreed with Sir Frederick Handley Page that the perspective drawings were proving invaluable in workshops. With regard to the suggestion that a hydraulic system could never be drawn in the first instance without fouling some parts of the mechanism, he stated that it was a practice in his firm to make working templates from an actual hydraulic pipe system which had been bent into position by one of the skilled mechanics working on the prototype.

Mr. N. E. Rowe (D.T.D., Ministry of Aircraft Production) said the motif of the paper was planning and commenting favourably on the need for standardisation of parts to which a great deal of attention was paid in the paper. He thought the method used in modifications of drawings was extremely satisfactory and pointed out that modification work resulted from routine development of existing types to meet new requirements thrown up by service use and could

therefore always be expected. With regard to the organisation, in his opinion this was of necessity formed to suit the personalities at the head of the firm, and the organisation put forward in the paper would therefore have to be modified slightly for each firm. The department of the experimental engineer was, however, extremely valuable and he would like to see it introduced into every aircraft firm's organisation. In the ordinary development work a large number of faults would be found out by flight experiments and it was necessary for this purpose to have highly skilled engineers to analyse such results. Moreover, having obtained such personnel it was essential that they should be put on work which was suited to them.

Mr. MENSFORTH commented that he did not think that the aircraft organisation should, or did, hinge around personalities. Americans visiting this country had, in fact, commented that too much attention was paid to personalities and insufficient time was paid to organisation here. The scheme put forward in the paper should do as well no matter what the personalities in the firm were. With regard to the need for trained engineers, he warned representatives against the tendency of training large numbers of aerodynamists as opposed to general engineers. In a firm it was advisable to obtain men with wide experience rather than specialists in one particular subject.

Mr. WESTBROOK (de Havillands, Ltd.) considered that the 5 per cent. cost of tooling was somewhat low, and in any case depended entirely on the type of aircraft being produced. He proposed the introduction of a project engineer, a position which was used in America, and might be extremely useful in this country. After the war, he thought a tooling figure of 10 per cent. would probably be extremely difficult to reach, and for this reason he did not think it wise for any particular aircraft to limit the tooling cost to a definite percentage.

Mr. MENSFORTH replied that the figure of 5 per cent. had been introduced largely in order to stress the necessity of specifying a definite limit, and he agreed with Mr. Westbrook that 5 per cent. was probably on the low side. While agreeing that the percentage must differ for various types of aircraft, he stressed the need on any particular type of determining a limit to the cost of tooling and to emphasise the importance of keeping below that figure.

Mr. PETTER stated that a project engineer under the title of assistant designer had been employed by Westlands for the last four years, one such person being responsible for each particular aircraft. In principle this assistant designer went through from the prototype stage to that of production in order that complete knowledge of the machine should be retained by him throughout its career. In practice, owing to the difficulty of obtaining suitable labour this was not actually done at the moment and an arrangement was made for the change-over of assistant designers to take place with a considerable overlapping period when the design passed to the chief production designer. In fact it was the practice now in certain cases to have as many as three or four " project engineers " for each machine, owing to the lack of wide experience and consequent segregation into specialist groups of much of the junior staff for which they were responsible.

Mr. HOLLIS WILLIAMS (Fairey Aviation Co.) said that he had found the paper to be extremely interesting and the analysis that had been made in the paper was long overdue. The object of any organisation was to obtain an absence of muddle, and as the organisation grew it had to become steadily more efficient to attain this end. With a small organisation the system of exchange of information need not be extensive, since personal contacts could be kept at frequent intervals. However, as the organisation grew, a stage arose when frequent meetings should be held to acquaint all designers interested in any aspect of the job with the present position. For this reason he thought it advisable that design and production engineers, jig and tool engineers and others should all start the job together.

Mr. PETTER agreed with this last proposal, which he thought had been stressed in the paper. In the author's organisation, meetings of the senior members of the design and other staffs took place every fortnight at the beginning of a project and weekly later on. Furthermore, they were invited at the introduction of any new project to send in their objections to any component of the previous machine. In this way many production difficulties might be eliminated at a very early stage.

Mr. MENSFORTH commented at this stage that a typical example of how production and design worked together, lay in the fact that production drawings were issued in the author's firm only twelve weeks after drawings of the prototype. He agreed that the need for the parallel working of design and production staffs was absolutely fundamental to reduce the development period on any aircraft.

Dr. KELLEY (Pressed Steel, Limited) stated that he was only acquainted with the production side of aircraft engineering. He thought that the company would do extremely well in reducing the development period to $2\frac{1}{2}$ years, and said that this depended largely on the standard of the available skilled workers. In his firm, which was concerned chiefly with car production, he found it very difficult to get the requisite number of skilled mechanics and consequently a lengthening of the development period occurred. It was arranged to issue fully detailed drawings to all the tooling departments at the same time and the time noted for complete tooling was in the region of ten weeks; this used to be 16 weeks, and he thought that by obtaining an optimum amount of skilled labour it might be reduced to eight weeks. With regard to the cost of tooling, his company, who were also producing a certain part for an aircraft, estimated that the cost of tooling for the whole aircraft was something like £500,000, which worked out at 1 per cent. of the overall cost of the aircraft produced. It was interesting to note that in the production of motor car bodies the cost of tooling was as low as one half of 1 per cent. of the total cost; of course, in this case, the number of bodies produced was very large. He commented that there was a point at which the labour-saving obtained by large tooling was counter-balanced by the cost of the tooling itself.

Mr. MENSFORTH replied that the Westland Aircraft Co. had never been fortunate enough to obtain sufficient skilled staff for its purposes, but stressed the point that for any organisation there was an optimum size of staff. In the United States the design staffs appeared to be much too unwieldy. He then drew attention to a remark in the paper that having any number less than this optimum was costly and instanced the case where two extra men in a staff of 50 could have reduced the prototype time by two months. Considerable difficulty also occurred in obtaining good draughtsmen and this had been partly cured by up-grading good men and by sub-contracting the drawing of complete sections of the aircraft to daughter firms with suitable assistance and liaison. In the case of a wing design this has been done relatively successfully, with a firm of no aircraft experience (on a tail unit it had been very successful with an experienced aircraft firm, the only difficulty being the different design standards occasionally to which the firms worked). With regard to Dr. Kelley's statement about an optimum tooling cost above which this was greater than the labour saving in production, he emphasised also the effect on development time due to the fact that there was a fair supply of the production to be saved by tooling semi-skilled labour, but the skilled mechanics necessary for the tool making were in short supply in wartime.

Mr. EGERTON-BANKS (Ministry of Labour) pointed out the difficulties which the Ministry of Labour had incurred owing to the remarkable growth of the aircraft industry, and, in his opinion, the general planning of the industry was a remarkable achievement with such a small number of available trained men.

Mr. WESTBROOK suggested that in view of Dr. Kelley's remark that the cost of tooling was £500,000, this would mean a contract of a magnitude which was

very seldom obtained in this country and, therefore, his cost of tooling could not be considered in any way an example of present-day practice.

Dr. KELLEY agreed that the project was probably larger than usual.

Air Vice-Marshal JONES (D/C.R.D., Ministry of Aircraft Production) questioned whether it was satisfactory to tool up for production on the prototype, since some part of such tooling might have to be modified after flight tests. He instanced the case of ailerons which normally needed considerable modification on the prototype to make them satisfactory in service. On the other hand, if a definite aileron had been found satisfactory, it was essential that the production article should be identical with it, and instanced several occasions in which the prototype aileron had proved satisfactory, whereas the production ailerons, owing to small differences in shape, had proved unsatisfactory in service. He also questioned whether the extra time taken in making jigs and tools for the prototype were justified, in view of the possibility of having to scrap them.

Mr. MENSFORTH replied that it was inadvisable to hold the prototype up by doing any tooling which would not be ready in time. Consequently the amount of production tooling that was used for the prototype was more or less negligible. Of course, even in the experimental shop, the mechanics had to make tools in many cases and some of these were frequently capable of being used for early production. The use of mould loft templates in prototype production was also in fact an important element of tooling used and proved early to the ultimate benefit of the whole development period.

Mr. FEARN (Westland Aircraft, Ltd.) stated that if it was uncertain whether a production order was forthcoming, no justification could be made for spending a large amount of money on prototype tooling. On the other hand, if the aircraft was definitely going into production it was well worth while to make jigs more complicated than would have otherwise been done in order to save labour in the later production process. With regard to the differences between production and prototype control surfaces he did not think that the aerodynamists were sufficiently advanced in their knowledge to be able to predict the effects of such changes as occurred between prototype and production machine and, in fact, his experience was that as the aileron was made to be more like the actual design the aerodynamics got worse.

Mr. MANSON (Ministry of Aircraft Production) disagreed with the previous speaker and stated that in the case of those components for which it was necessary to make the production unit identical with the prototype, it was justifiable to risk the possibility of the whole jig being scrapped on account of unsatisfactory ailerons. He asked why the components of an aircraft shell could not all be made with straight line surfaces, since this would ease the jigging problem which would only have to deal with curvature in one direction. Particularly in time of war, designers should bear in mind the necessity for reducing production time as much as possible. He raised the question as to what the authors of the paper considered to be an optimum staff; there was not sufficient emphasis on the young trained detail draughtsman or the supervision of them; in his opinion more training of this class of draughtsman would greatly improve the aircraft design.

Mr. SERBY (Ministry of Aircraft Production) spoke on the discrepancies between the performance of production and prototype ailerons. With the present method of fitting tapes, etc., to the aileron to obtain the required balance, it was not surprising that the production article was not as satisfactory as that obtained on the prototype. Quite obviously, if any cutting of the aileron was to be expected on the prototype, it was very unwise to carry out prototype tooling. However, the tendency now was to design control surfaces which were not so susceptible to slight changes of shape or for using powered controls and for this reason tooling would, in future, be more satisfactory.

Mr. MENSFORTH replied that, while the tooling that was carried out for the prototype did not materially accelerate the production to first flight stage of this machine, the time saved in later series production was quite considerable, so long as the number of parts which were likely to change when production was started was not so great. With regard to the optimum size of the engineering department of a firm, this depended essentially upon the type of aircraft under consideration. In his own experience, which covered only the medium sized fighter machine, he thought the optimum size of technical staff was about 250 people. This was very much smaller than the average American concern had. He agreed with Mr. Fearn that detail draughtsmen should obtain more training than they were now getting. He thought it essential that they should serve as apprentices and become acquainted with practical work, *e.g.*, foundry practice and machining. The examples shown on the screen of advice to draughtsmen in the D.O. standards book of, for example, the pitfalls to be watched for in a casting design was a poor alternative only to be employed temporarily until the industry had trained men in the manner suggested.

Mr. PETTER stated that the methods of balancing controls, to which Mr. Serby referred, would be extremely useful, but it would be some years before designers could get away completely from all manual balance on ailerons. At the moment it appeared that such things as thickness and trailing edge angle were of vital importance in obtaining the correct balance and it was vital that the prototype and production article should be similar in these respects. With regard to the necessity of straight line geometry on aircraft, he thought that most firms made everything with straight line geometry when it was aerodynamically allowable as a wing plan particularly as in this case the method lent itself greatly to the use of mould lofting. He did not think, however, that it was satisfactory to make fuselages of a limited number of straight lines. In view of the probability of increased flight testing, he thought it would be essential to budget for increased numbers of technical staff to be available to investigate the results.

Mr. M. LANGLEY (Flight Refuelling, Ltd.) was appalled at the time necessary to construct the first prototype, particularly when it was remembered that an early Schneider machine was designed and flown within a period of twelve weeks. He thought that designers were paying too much attention to the equipment end of aircraft, which, in his opinion, was not necessary for first flight tests as long as the necessary space and the weight were available. From this point of view it was essential in first flight tests simply to have the shell of the machine finished. He advocated the naval dockyard method of training, where research students were not brought up entirely in the university, but were acquainted also with dockyard technique as well. In his organisation he had diluted large numbers of mechanical engineers, giving them two to three months' training on installation work prior to joining the design staff. Women workers had been given a short training and had then been spread around the detailing staff and worked under strict supervision. University men, on the other hand, who arrived at the firms were not allowed to obtain practical experience such as two or three years' shop apprenticeship as had been the case prior to the war, but were put upon calculations immediately. Consequently these men could not be expected to have the same practical outlook as they would normally have had. With regard to Sir Frederick Handley Page's suggestion that skilled mechanics had favoured the use of three-view drawings, he thought that the drawings which should be given to the unskilled workers should be of a very simple nature and include full working directions. Mr. Langley advocated the issue from the drawing offices of pieces of metal bent and drilled correctly as samples to help the unskilled worker.

Mr. PETTER answered that, as opposed to the Schneider machine, the modern aircraft was subject to an extremely severe specification and the majority of the equipment was essential for the operational use of the machine.. The time to

design the equipment was often as great as that of the basic structure. It was an American experience that 45 design man hours per pound weight of aircraft were required to produce the prototype, while his own experience was that it took something like 35 man hours compared with the two to three man hours for the Schneider machine. The Schneider machine, in any case, was only released for an extremely narrow category of duties and was probably not satisfactory for general flying; it would be unlikely to have proved acceptable to an R.A.F. test establishment. With regard to the making of much more detailed drawings, and templates, he thought that the time taken to produce these detailed drawings would outweigh the saving in time in production.

Mr. CUSS (Gloster Aircraft, Ltd.) raised the question of what design staffs should be given to do when not working on an actual project. It was unsatisfactory to invent jobs for them and then state at a later date that the project had fallen through. As a result of this practice, the urgent job was often not given the enthusiasm that it needed. He thought a good solution would be for designers and draughtsmen to volunteer to go to work in the shops, whenever their services were not required on an actual project. Their experience would be greatly enhanced in this way and their enthusiasm would still be maintained. Unfortunately, he thought that the enthusiasm which occurred in a firm varied inversely with the size of the staff. Commenting on the time taken to produce a prototype owing to the necessity of a detailed stressing of different parts, he suggested that the stressing of the prototype should be left entirely to a man of great experience to decide by eye, and that the first prototype should be strength tested to destruction to determine that there were no flaws in the strength estimates thus made. By this means he thought that a satisfactory prototype could be produced in about one third of the time.

Mr. WESTBROOK asked whether time study was used sufficiently to convince shop superintendents of the amount of labour necessary for any job.

Mr. MENSFORTH agreed that this was an extremely important subject; the whole matter of rate fixing and the attitude of labour to it could materially affect the time of production development. In the U.S.A. thorough time study was made, but in general no incentive system was worked and as a result it was doubtful if these were now getting the full benefit from it. The answer to Mr. Cuss's statement about the enthusiasm of staffs was to have units of such a size as to maintain personal contact. He had had no experience of what to do with aircraft draughtsmen during idle periods, but he had no doubt that if such idleness occurred, the advisable procedure would be to offer the services of these draughtsmen to another firm by a sub-contract; this had been done successfully in at least one case.

Mr. VOKES (Vokes, Ltd.) considered that equipment manufacturers should be called in at a much earlier date than was now the practice, and he thought that the parent firm should ask the manufacturer to design the whole installation of a particular piece of equipment in conjunction with the parent firm. In this way, and in this way only, was it possible to prevent those major miscalculations which occurred at present. In view of the statement that 45 per cent. of the design of an aircraft consisted of equipment, this certainly appeared to be worth while. A further plea was made that sufficient information should be given on the use of the equipment, since only then could it be designed to the full satisfaction of the users of the aircraft.

Mr. PETTER agreed that equipment makers should be brought in at the earliest moment, and stated that in his firm the chief development designer spent about half his time in dealing with equipment manufacturers. One of the greatest difficulties arose from the fact that a large portion of the equipment was so new that designers had insufficient information on the space and weight it incurred. However, in view of the diversity of equipment which went into an aircraft it was essential that a firm should have a tight hold on the designs proposed by

the various manufacturers. With regard to the idea of stressing by eye, he agreed that it had great value when such people could be found; in his opinion, the number of people who were capable of doing this was very limited and were not present in large numbers in a stress office. In any case it was essential that the pilot and the M.A.P. should be satisfied with regard to the safety of his aircraft before flying.

Mr. WOODFORD (Ministry of Aircraft Production) considered that strain gauging would play an important part in the time necessary to produce a prototype, since the stressing in any component could be closely determined by this technique in flight or in bench tests.

Mr. BOUND (Dowty Equipment, Ltd.) urged the need for the standardisation of parts and stated that the first step towards standardisation was that of the small units. He emphatically stated that screw threads should be standardised, a procedure which could be carried out without any sacrifice in weight. Another point raised was that no reference was made in the paper to the American practice of having a chief engineer to approve all the mechanical equipment on an aircraft.

Mr. PETTER replied that the experimental engineer was in a position to test and express disapproval if necessary of mechanisms and parts which he considered to be of doubtful merit.

In answer to a request by Mr. Gouge, Mr. MENSFORTH said that the weights of the machines under consideration were given in Fig. 1 and that a large amount of other data was available which he would like to see compared with that of other firms. A rough figure for the cost of a production airframe was of the order 25/- per pound weight of the aircraft. It was difficult to estimate on a similar rough basis the cost of prototypes, except as an addition to this figure, but he thought a very rough figure might be £5 per lb. weight; approximate estimating could be carried out on individual components on a weight basis by comparison with previous experience, weighted by size, etc., and this would be adequate for initial budgetting.

Mr. GOUGE thanked the authors of the paper and the members of the aircraft industry for the lively discussion which had taken place, and called the meeting to a close.

Mr. G. BEAUMONT (of Blackburn Aircraft, Ltd.) (*communicated*): The paper is an extremely interesting one and the authors are to be congratulated on having studied the problem in such detail. He was particularly interested in the minimum development period from the stressing standpoint. Whilst appreciating the complexity of loading conditions associated with modern high speed, highly manœuvrable aircraft, he was of the opinion that unless some attempt is made to simplify the official stressing requirements, the stress office will always be a bottle-neck and attempts to speed-up in other sections of the design office will be nullified. The recent revision of stressing requirements has tended to increase the work and time involved in stressing some components. The minimum number of cases to be investigated in the stressing of an undercarriage is forty-five as compared with nine in the requirements previous to the revision. New tail-wheel requirements involve an investigation for eighteen cases as compared with three in the old requirements. The increase in work extends beyond the component concerned, as the loads have to be absorbed into the supporting structure. Whilst agreeing that there was probably some need for revision of the old requirements, he considered that, in general, the additional strength required could be obtained by an increase in the overall factor. The J.A.C. Committee responsible for revising strength requirements should be asked to consider more the practical application.

The system of issuing drawings without a stress-check is a dangerous one and unfair to the average draughtsman who has little knowledge of the load system and the paths which the loads must take. The alternative system by

which detail drawings pass through the stress office is liable, despite careful planning, to cause serious obstruction in the flow of drawings passing from the design office to the works.. One method of overcoming this difficulty is to issue provisional drawings for ordering, planning and processing purposes before the drawing is finally cleared by the stress office. The provisional drawings are then withdrawn.

Changes in design during production should be classified with a given order of priority.

(1) Changes necessary to increase the safety, improve the performance or extend the duties of the aircraft.

(2) Those considered necessary to improve production.

The stage of introduction of such changes should be left to the mutual agreement of the chief designer and works manager, and is influenced by the necessity and value of the change compared with the trouble caused in production.

A point which is not sufficiently emphasised in the paper, is the planning of floor space and plant layout. Properly planned floor space is a great asset and the need for intelligent planning becomes greater as it becomes necessary to increase output, without the means of expanding floor space. Large scale production requires the transport of large quantities of material between departments, and areas which should be used as working areas are liable to become storage places. Few design offices in this country were initially planned to accommodate the large staffs now employed, with the result that draughtsmen and stressmen are working under cramped conditions with little space in which to spread out drawings. This tends to create confusion and inefficiency.

The first consideration in sub-contracting is that the part or assembly to be sub-contracted will give no trouble to the parent firm. It is essential that the only components which are sub-contracted are those in which all the troubles and difficulties have been overcome, and those which can be simply produced.

Mr. PETTER (*communicated reply*): It is agreed that the official stressing requirements are becoming very numerous as to the cases to be considered, and that for undercarriage and tail wheel stressing some contraction of the number of cases should be possible.

So far stress work has not proved a bottle-neck, but any further considerable extension of the cases to be considered may be serious.

The system of issuing advance provisional drawings for ordering, planning, and processing purposes, advocated by Mr. Beaumont is considered to be a good one providing care is exercised in the extent of the circulation of these provisional drawings.

TORSIONAL VIBRATION ANALYSIS OF SYSTEMS CONNECTED BY FLEXIBLY-MOUNTED EPICYCLIC GEARING.

(AN EXTENSION OF THE DYNAMIC STIFFNESS METHOD.)

By R. G. Manley, B.Sc., Grad.R.Ae.S.

I. Introduction.

The author has described elsewhere (reference 1) the general principles of the dynamic stiffness method of analysing torsional vibration problems. Amongst the systems treated were those involving simple spur or helical gear-steps. The method can also be applied, however, to deal with epicyclic gearing, making proper allowance for the effect of flexibility in the gear-housing. The present paper outlines this extension.

A similar method may be used to allow for housing flexibility in normal spur gearing.

II. General Theory—Idealised Gearing.

An epicyclic gear train with simple planet wheels can be represented as shown in Fig. 1. There are three shafts (1, 2, 3) each capable of rotation, although in normal usage the rotation of one of them will be limited to that possible against fixing restraint. It is required to find the relation between the dynamic stiffnesses at the three shafts. Transference of the reference point through an inertia is easily effected, as described in the previous paper; thus the inertias of the annulus, carrier and sun-wheel can be omitted from this preliminary investigation, which is concerned with the inherent properties of the gearing as a compound coupling. It will be shown that the inertia of the planet wheels can be distributed amongst the other members; attention will therefore be confined, for the moment, to an idealised gear without inertia.

Referring to Fig. 2, Z_2 and Z_3 are the dynamic stiffnesses of the sub-systems attached to the carrier and sun-wheel respectively. It will be understood that these sub-systems will include the relevant inertias of the gearing. Z_1 is the equivalent dynamic stiffness at the annulus. If x, y, z are the amplitudes of angular vibrations of the annulus, carrier and sun-wheel as shown in Fig. 3, and a, s are the pitch radii of the annulus and sun-wheel, it is easily shown that

$$(a+s)\,y = ax + sz \qquad . \quad . \quad . \quad . \quad . \quad (1)$$

Further, if a torque of amplitude T_1 is applied to the annulus, the torque outputs T_2 and T_3 at the carrier and sun-wheel respectively are given by:—

$$\left.\begin{aligned} T_2 &= \left(\frac{a+s}{a}\right) T_1 \\ T_3 &= -\frac{s}{a}\, T_1 \end{aligned}\right\} \qquad . \quad . \quad . \quad . \quad . \quad (2)$$

positive directions of torques and displacements being as shown in the diagram, and negative amplitudes being interpreted in the usual manner as indicating anti-phased vibrations.

Now, if the torque T_1 maintains the amplitude of vibration x, the following three relations hold:—

$$\left.\begin{aligned} Z_1 &= T_1/x \\ Z_2 &= T_2/y \\ Z_3 &= T_3/z \end{aligned}\right\} \qquad . \quad . \quad . \quad . \quad . \quad (3)$$

and from equations (1), (2), and (3) the relation is obtained:—

$$\frac{1}{Z_1} = \left(\frac{a+s}{a}\right)^2 \left(\frac{1}{Z_2}\right) + \left(\frac{s}{a}\right)^2 \left(\frac{1}{Z_3}\right) \quad . \quad . \quad . \quad . \quad (4)$$

This is the required relation. Rewriting it in the form

$$\frac{1}{Z_1} = \frac{1}{Z_2 \{ a/(a+s) \}^2} + \frac{1}{\{ Z_3 (a/s)^2 \}} \quad . \quad . \quad . \quad . \quad (5)$$

and comparing (5) with the formula for transference of the reference through a light shaft, it is evident that the system of Fig. 2 can be represented as shown in Fig. 4. The epicyclic gear is replaced by a simple spur gear having the

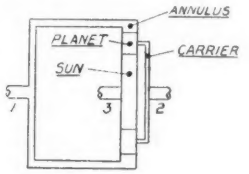


FIG. 1

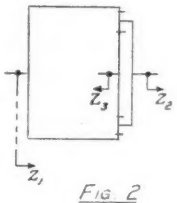


FIG. 2

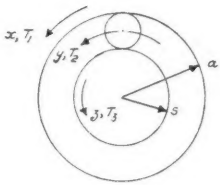


FIG. 3

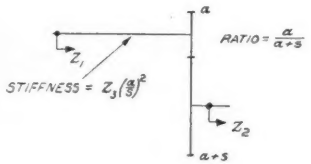


FIG. 4

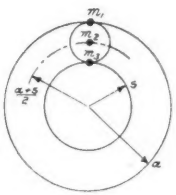


FIG. 5

same gear ratio $a/(a+s)$, connecting the annulus and the carrier; the annulus being attached to the gear through a shaft having the stiffness $Z_3 (a/s)^2$. This stiffness is, in general, a function of the frequency of vibration, being proportional to the dynamic stiffness of the sub-system attached to the sun-wheel (including the inertia of the sun-wheel and the relevant part of the inertia of the planet wheel).

In the case where the sun-wheel is fixed rigidly, Z_3 is infinite, and equation (5) reduces to:—

$$Z_1 = Z_2 \left(\frac{a}{a+s}\right)^2 \quad . \quad . \quad . \quad . \quad . \quad (6)$$

which is the normal form for transference of the reference point through a simple gear-step with the ratio $a/(a+s)$.

It may be noted that the system could be represented in a form alternative to the arrangement in Fig. 4, the gear-step connecting the annulus and sun-wheel and the shaft having a stiffness $Z_2 [a/(a+s)]^2$. This form might be preferable in certain cases. In either form, two members A and B are linked through a shaft and simple spur gear, the stiffness of the shaft being the dynamic stiffness of the sub-system attached to the third member C, multiplied by the square of the gear-ratio of the epicyclic train calculated as if B were fixed; and the ratio of the gear step is that of the epicyclic train calculated as if C were fixed. Thus, in Fig. 4, A is the annulus, B the carrier, and C the sun-wheel; in the alternative mentioned, B is the sun-wheel and C the carrier.

It may also be noted that the same general method of attack can be applied to the calculation of the effects of gear-housing flexibility in the case of gears not essentially epicyclic.

III. Distribution of Planet-Wheel Inertia.

In any dynamic investigation it is legitimate to replace a body by a dynamically equivalent body or system of mass particles. Two bodies or systems of mass particles are dynamically equivalent if their total masses, positions of centroids, and principal moments of inertia about the centroids are the same.

It is convenient in the present study to replace the planet wheels by a special system of mass particles. First, so far as torsional vibration is concerned, the planet wheels can be considered as aggregated into one wheel, having a mass and polar inertia equal to the total mass and polar inertia of the wheels. The mass and polar inertia are denoted to m, J_p. Consider the system of three mass particles depicted in Fig. 5, one mass being at the centre of the planet wheel and the others at the points of contact of the pitch circles. If p is the pitch radius of the planet wheel, the conditions given in the first paragraph above are:—

$$m_1 + m_2 + m_3 = m$$
$$m_1 = m_3$$
$$(m_1 + m_3)\, p^2 = J_p.$$

These conditions are satisfied if:—

$$\left.\begin{aligned} m_1 = m_3 &= J_p/2p^2 \\ m_2 &= m - J_p/p^2 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

If the particles have these masses, they comprise a system which is dynamically equivalent, so far as torsional vibration is concerned, to the planet wheel. The wheel is therefore regarded as being replaced by such a system of mass particles, m_2 being attached to the carrier at the planet wheel axle, and m_1 and m_3 to the annulus and sun-wheel at the pitch radii. The inertia of the planet wheel is then fully accounted for if additions are made to the inertias of the other members as follows:—

$m_1 a^2 = \frac{1}{2} J_p\, (a/p)^2$ added to the annulus,
$m_2 c^2 = (m - J_p/p^2)\, \frac{1}{4}(a+s)^2$ added to the carrier,
and $m_3 s^2 = \frac{1}{2} J_p\, (s/p)^2$ added to the sun-wheel.

It will be noted that all these inertias are attached to the shafts 1, 2, 3 of Fig. 1. The necessity for such a substitution arises from the fact that the planet wheel is not itself directly attached to any of these shafts.

IV. Actual Reduction Gear.

The normal arrangement of an epicyclic reduction gear for an aircraft power plant is shown in Fig. 6. It is, of course, immaterial which of the two end wheels of the train is regarded as being the annulus, and which the sun-wheel; one of them is connected to the engine, and the other is carried by the gear-housing. The planet wheels are carried on a spider mounted on the propeller shaft.

The flexibility of the gear-housing can be represented by a torsional spring of stiffness C. This is always practicable as a first approximation, the value

of C being determined experimentally or by calculation. If necessary, a more accurate allowance can be made by replacing the constant C by the dynamic stiffness of the gear-housing referred to the sun-wheel. With this reservation, the gear system can be represented as shown in Fig. 7. The inertias J_1, J_2, and J_3 represent the inertias of the annulus, carrier and sun-wheel, with the additions listed in section III, and are rigidly attached to the corresponding members of the gear train. Thus, if J_a, J_c and J_s are the inertias of the annulus, carrier and sun-wheel respectively,

$$J_1 = J_a + \tfrac{1}{2}J_p\,(a/p)^2$$
$$J_2 = J_c + (m - J_p/p^2)\,\tfrac{1}{4}\,(a+s)^2$$
$$J_3 = J_s + \tfrac{1}{2}J_p\,(s/p)^2.$$

Now, if the frequency of vibration is $(w/2\pi)$ C.P.S., and Z_P is the dynamic stiffness of the propeller, equation (4) gives:—

$$\left.\begin{aligned} 1/Z_1 &= \{\,(a+s)/a\,\}^2\,(1/Z_2) + (s/a)^2\,(1/Z_3) \\ \text{where}\quad Z_2 &= Z_P - J_2 w^2 \\ \text{and}\quad Z_3 &= C - J_3 w^2 \end{aligned}\right\} \quad . \quad . \quad (8)$$

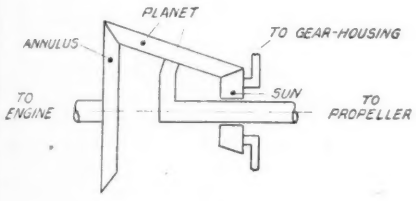


FIG. 6

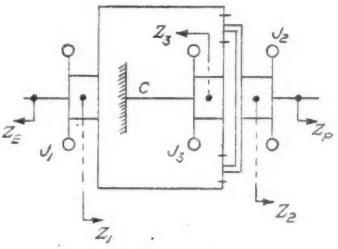


FIG. 7

The dynamic stiffness Z'_1 at the point of attachment of the crankshaft is given by:—

$$Z'_1 = Z_1 - J_1 w^2 \quad . \quad . \quad . \quad . \quad . \quad (9)$$

and if Z_E is the dynamic stiffness of the engine, the condition for resonance is

$$Z_E + Z'_1 = 0 \quad . \quad . \quad . \quad . \quad . \quad (10)$$

From equation (10) the natural frequencies of torsional vibration can be calculated.

V. Acknowledgment.

The author's attention was drawn to the problem by an article by W. Benz (reference 2). In this article the distribution of the planet wheel inertia was described, and a representation similar to Fig. 4 was shown. The proof of the validity of this representation given was not very convincing, however, and no clue was given as to how the result was obtained. Furthermore, the system actually treated corresponded to the case C = constant, and there was no attempt to obtain the general relation (4). It is always a relatively simple matter, however, to fill in details and extend a method, once the general method of attack has been shown, and the author desires to give full acknowledgment to Benz for the result, reserving his claim for original treatment to the method of derivation. The present paper is offered as an extension to the general theory of dynamic stiffnesses, and as an analysis of the generalised epicyclic gear, in which no member is necessarily fixed rigidly.

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1. Manley, R. G. "Dynamic stiffness and effective inertia methods in modern torsional vibration theory." Journal of the Royal Aeronautical Society, January, 1943.
2. Benz, W. "Natural frequencies of torsional systems, in particular elastically-mounted epicyclic gears." Luftfahrtforschung, February 27th, 1943.

CORRESPONDENCE.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

DEAR SIR,—In the May issue of the Journal of the R.Ae.S. I read with great interest the lecture given by Mr. E. T. Jones on Flight Testing Methods.

To the congratulations he received from others I would like to add my own. I was particularly interested in the lecturer's reply to Mr. Lipscombe's remarks.

He is reported to have said that he did not like "this flying-boat business," and, "if he were to differentiate he might say something which would tell against the flying-boat and he did not wish to do that."

It seems to me that those words rather confirm Mr. Lipscombe's fears.

If there is anything to say against the flying-boat surely it should be said and the subject Aeroplanes versus Flying-Boats be ventilated.

In my opinion the aeroplane is not against the flying-boat nor is the flying-boat against the aeroplane.

Each type of aircraft can be of use where the other can not in certain circumstances.

The great continents with their teeming populations and excellent aerodromes will provide a greater field for aeroplane production than the oceans, seas, lakes and sheltered waters will provide for flying-boat production.

Those who have experience only of aeroplane design and construction need not fear that money spent by the Government on flying-boat development will take the gilt off their gingerbread.

We know that aeroplanes can be designed to offer less head-resistance than flying-boats as designed to-day.

We know that it is more convenient to step into an aeroplane on the aerodrome than it is to board a flying-boat anchored some distance from the shore when the water is rough.

We know that multi-engined aeroplanes can fly with great safety from, say, an aerodrome in America to an aerodrome in Europe and cross the oceans in many directions, but in a forced landing at sea I, and many others, would prefer to be in a flying-boat, even though the boarding had been more difficult and the speed of transit a few miles slower.

Aeroplanes can be made to float in the event of a forced landing at sea, but they cannot take off again.

In a moderate sea, such as generally prevails in the South Atlantic, the flying-boat can alight and conserve its petrol, listen for submarines, watch for smoke on the horizon which might come from an enemy ship. It can pick up ship-wrecked persons, so well demonstrated during this war and the last war. It can be flown over land with the same degree of safety as an aeroplane flown over sea and the aerodromes it uses cannot be pitted with bomb craters and so rendered useless for many days.

Where there is sheltered water flying-boats can be used whilst landing grounds are temporarilly unfit for use.

The flying-boat can be developed to far greater carrying capacity than can the aeroplane. It promises to be the great freight carrier over the oceans. Not to take a step too far, consider the problems involved in designing and building a flying-boat of one hundred tons airborne weight and an aeroplane of the same carrying power. The chassis of the aeroplane under present designing methods would be very heavy indeed, and take a toll upon the paying load.

I do not assume that this handicap will stand much in the way of the building of heavier aeroplanes than are now flying. The use of electron metals in a caterpillar landing chassis and other methods and materials may aid to solve the problem.

In the design of large flying-boats that problem of design and complication of structure does not exist. The flying-boat lives and as it lives it grows. It will be the " Queen Mary " of the air.

We must not be pessimistic about the future of the flying-boat. If we neglect its fullest possible development we shall be left behind by other nations who will develop it.

After the war, 1914-1918, official technical opinion held the view that no aeroplane or flying-boat above 10,000 lbs. all up weight would prove advantageous in performance. Short's built the " Sarafand," 75,000 lbs. It was, when produced, the fastest flying-boat in the world. It paved the way, not only for the " Empire Flying-Boat " and the " Sunderland," but for the giant aeroplanes which are being used to-day.

There will only be danger of neglecting flying-boat development if official technical opinion decides that the aeroplane can fulfil all the requirements of air transport.

OSWALD SHORT, F.R.Ae.S.

STRUCTURAL FEATURES OF GERMAN AIRCRAFT.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

SIR,—Though I do not wish to belittle the pioneering effort of the late Professor Hugo Junkers and his very able associates up to 1918, it would neither seem justified, nor fair, to attribute to his efforts such a value as the authors do.

Those familiar with the metal structures of the Zeppelin airships of the period and with the early work of Dr. Claude Dornier (by upbringing a structural engineer, and originally, a promoter of steel strip construction) will agree that without the prior pioneering efforts of Dornier and the Zeppelin engineers (Jaray, for instance) and without the workshop experience borrowed from the Zeppelin people, Professor Junkers would have failed during the period under consideration.

Incidentally, the tubular construction of cantilever wings has originated less from structural considerations than from the endeavour to make the wing structure safe against hits from bullets and splinters. In this connection, the names of Professor G. Madelung and Reuter should be mentioned. This bullet-proof tubular structure was found to be practical and was hence incorporated into transport aeroplanes.

Dornier designed and constructed all-metal aeroplanes with cantilever wings which had, as well as in their fuselages, completely stressed skin structures as far back as 1916/17 (Do. D.I. single-seater fighter, for instance). This was at a time when Junkers had failed in his attempt at stressed skin design, and had to change over to a partly stressed corrugated skin covering a tubular frame work, and to the use of aluminium light alloy.

The view that metal might be considered preferable to wood as a basic material can scarcely be considered a discovery of Professor Junkers. There have been many earlier attempts at all-metal aeroplanes, not only in Germany, but also in this country and in France. An aeroplane which was (including the wing covering) completely built of aluminium alloy, with the sole exception of the airscrew and the seat cushions) was exhibited and actually flew in 1912; its fuselage was a completely stressed skin structure. Dornier never considered wood, and he began to construct aeroplanes several years before Junkers did.

Nor are cantilever wings the invention of Junkers. Levavasseur, the famous designer of the " Antoinette " monoplanes, had, in 1911, constructed a low-wing

monoplane with cantilever wings and a trousered undercarriage; it had a three-spar wing structure. Several other attempts, among them Coanda and Baumann, were made years before Professor Junkers appeared on the scene. In one instance, petrol tanks were mounted inside the structure of a cantilever wing, an anticipation of Junkers's famous patent of 1911.

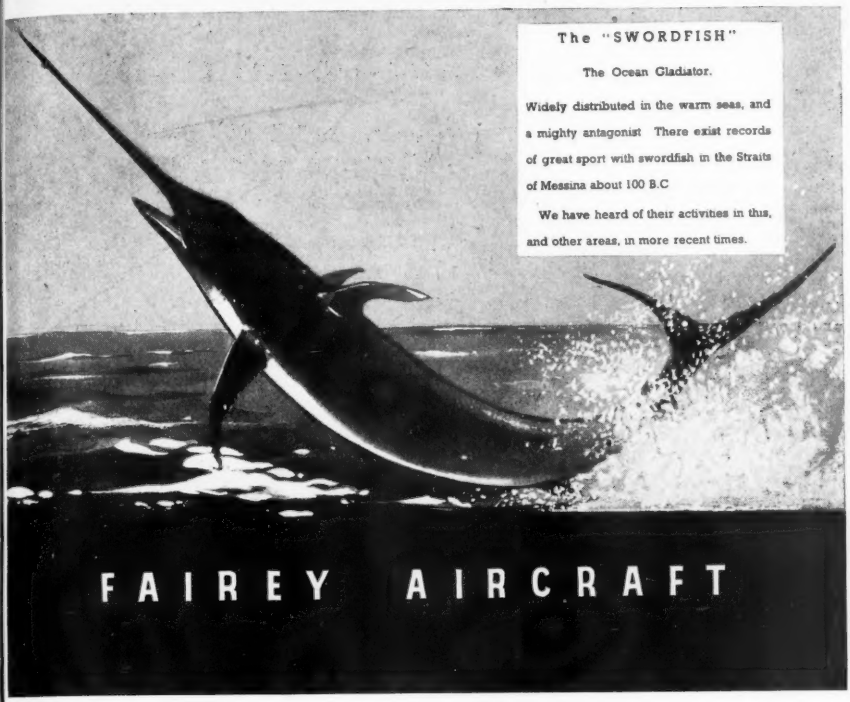
A. Rohrbach, a former assistant of Dornier and a collaborator of the late Professor Alexander Baumann, also designed and constructed all-metal aeroplanes which in layout and structure showed very modern design features, including stressed skin details; this dates as far back as 1917.

In connection with the earliest aeronautical studies of Professor Junkers, the influence of Professor Hans Reissner (New York) should not be forgotten. It was Reissner, the founder of the science of aircraft statics in Germany, who incorporated in the 1910 design of his " tail-first " monoplane a wing which had a skin of corrugated light alloy sheet (acc. to the German Patent Spec. No. 222,226 of 1909, which contains also the basis for the original attempts of Junkers at a stressed skin structure, as mentioned by the authors). This wing was constructed during 1910/11 in the workshop of Professor Junkers, and subjected to proof loads prior to the flying tests. Also the so-called Junkers wind-tunnel at Aix-la-Chapelle was mainly based upon the design of Professor Reissner (whom the industrious Junkers propaganda has scarcely ever mentioned).

With regard to pioneering work in German aeronautics, the merits of Professor Hans Reissner as an experimenter and as a theoretical investigator, and of Dr. Claude Dornier as an aircraft designer deserve more mention, since the propaganda of the Junkers works seems to have achieved its aim in boosting the valuable achievements and tenacity of the late Professor Junkers beyond all proportion to the actual facts (which, however, can easily be verified).

I am, Sir, Yours faithfully,

A. R. Weyl, A.F.R.Ae.S.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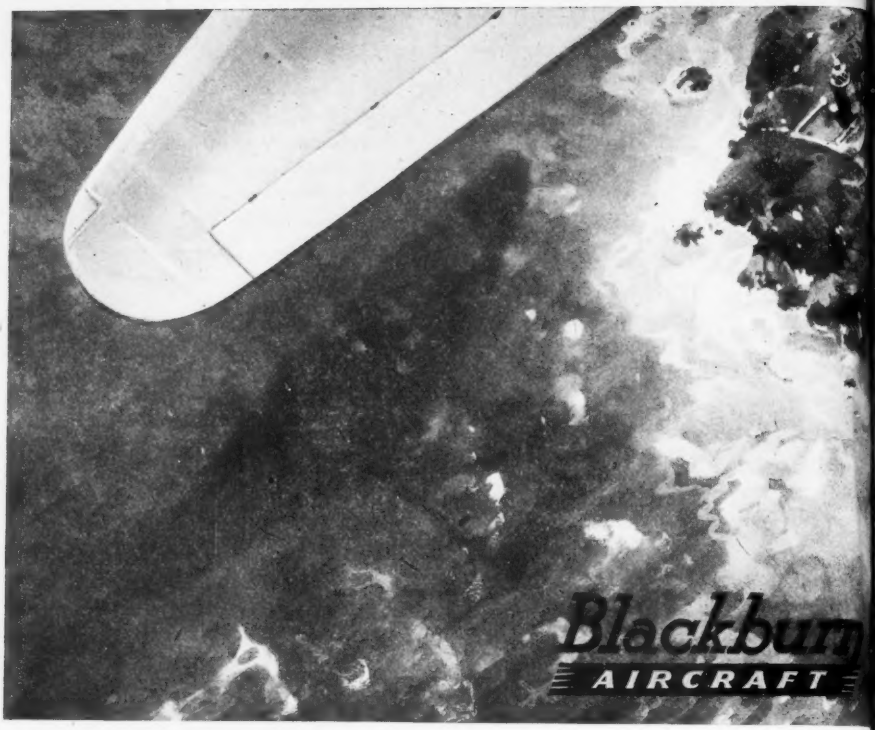

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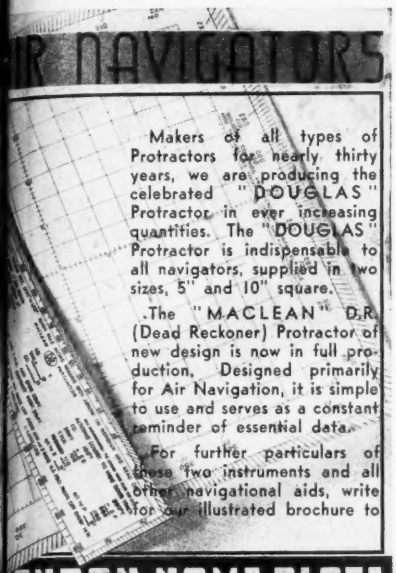

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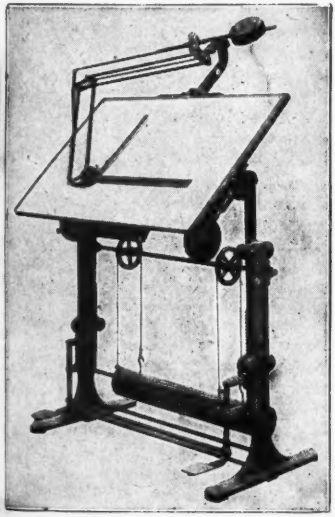

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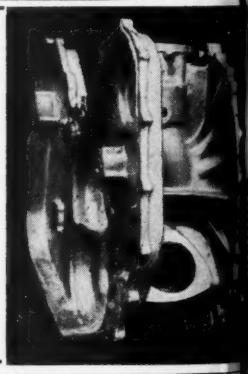

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